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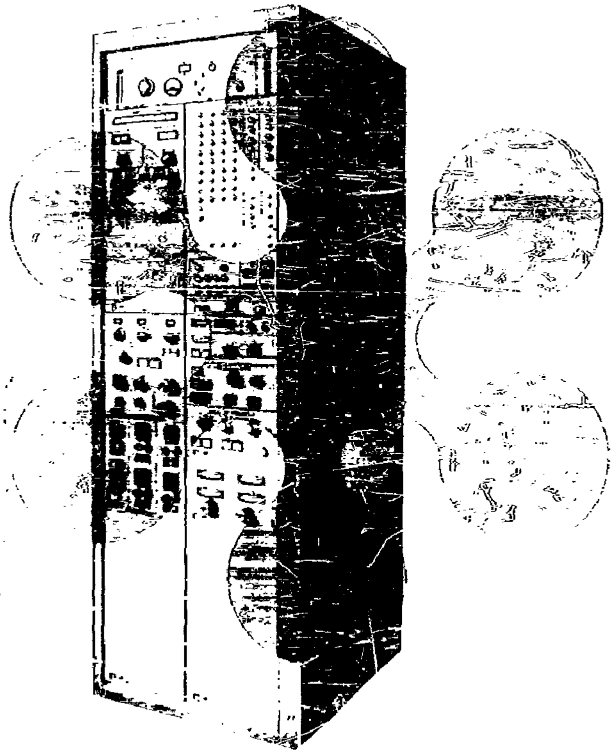
WDL-TR1850

28 SEPTEMBER 1962

TECHNICAL DOCUMENTARY REPORT



CONTRACT NO. AF04 (695) - 113
AIR FORCE SPACE SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
INGLEWOOD, CALIFORNIA

MULTIPURPOSE RECEIVER SYSTEM DESIGN STUDY

FINAL REPORT

PHILCO

A SUBSIDIARY OF Ford Motor Company

WESTERN DEVELOPMENT LABORATORIES

In reply cite:
RB/TWC/das
28 September 1962

SUBJECT: Contract AF04(695)-113
Submission of WDL-TR1850 as a deliverable item.

TO: Commander
Space Systems Division
Air Force Systems Command
United States Air Force
Air Force Unit Post Office
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ATTENTION: Technical Data Center (10 copies)

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REFERENCES: (a) Contract AF04(695)-113, Exhibit "A"
(b) AFBM Exhibit 58-1, Paragraph 4.2.2
(c) AFSSD Exhibit 61-27A, Paragraph 1.2.1.2

In accordance with the requirements of reference (a), (b), and (c), we are forwarding ten (10) copies of the following document:

Title	Number and Date
Multipurpose Receiver Design Study Final Report	WDL-TR1850 28 September 1962

PHILCO CORPORATION
Western Development Laboratories

R. W. Boyd

R. Boyd
Manager, Contracts Management

WDL-TR1850
28 September 1962

TECHNICAL DOCUMENTARY REPORT

MULTIPURPOSE RECEIVER DESIGN STUDY FINAL REPORT

Prepared by

PHILCO CORPORATION
Western Development Laboratories
Palo Alto, California

Contract AF04(695)-113

Prepared for

AIR FORCE SPACE SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Inglewood, California

ABSTRACT

PHILCO WDL-TR1850 UNCLASSIFIED
MULTIPURPOSE RECEIVER
DESIGN STUDY (FINAL REPORT) 330 pages
28 September 1962 Contract AF04(695)-113

The multipurpose receiver discussed in this final report is designed to meet functions required of tracking stations for the majority of anticipated space programs through 1970. A detailed design study is presented as a guide for final development of a multipurpose receiver to function in the frequency bands of 100 mc to 10 Gc. Discussions include the use of standard detection methods plus phase and frequency feedback techniques for detection of received signals including wide-band FM, narrow-band FM, PM, AM, and multiple angle modulations. Reliability and maintainability evaluations are also included in the report.

FOREWORD

This Technical Documentary Report on Definitive Contract AF04(695)-113 has been prepared in accordance with Exhibit "A" of that contract and Paragraph 4.2.2 of AFBM Exhibit 58-1, "Contractor Reports Exhibit," dated 1 October 1959, as revised and amended.

This report was prepared by Philco Western Development Laboratories in fulfilling the requirements of Paragraph 1.2.1.2 of AFSSD Exhibit 61-27A, "Satellite Control Subsystem Work Statement," dated 15 February 1962, as revised and amended.

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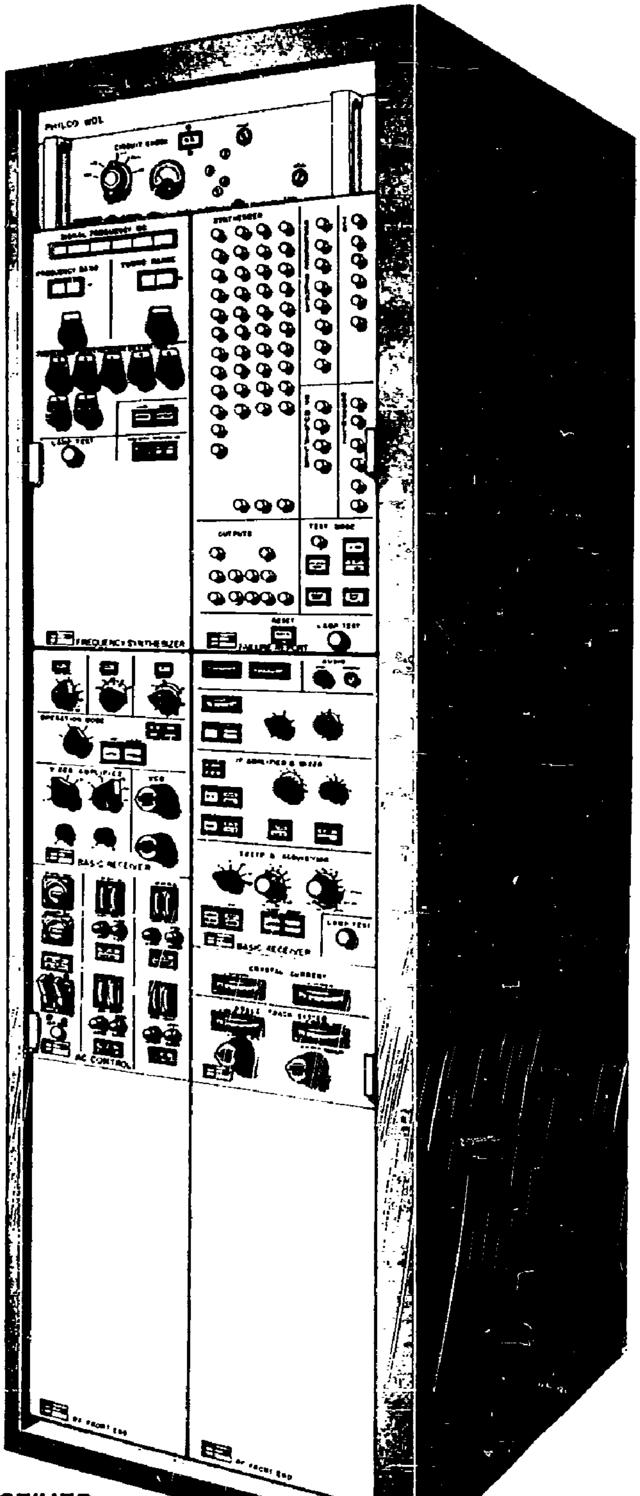


PHILCO WDL
MULTIPURPOSE RECEIVER

PHILCO

WESTERN DEVELOPMENT LABORATORIES

SECTION 1
INTRODUCTION

1.1 GENERAL

The Multipurpose Receiver Design Study presented in this final report is based on established requirements and specifications for Air Force space programs.

In satellite programs, optimum performance of ground equipment is essential because communication links are critical. It is important, therefore, that the multipurpose reciever be designed to provide optimum performance.

Understanding this, Philco Western Development Laboratories (WDL) has attempted to design a multipurpose receiver that is capable of handling a variety of signals and frequencies without compromise or degradation of the receiver's performance.

This final report discusses the methods and techniques that Philco WDL has employed to accomplish such a receiver design. The report also contains discussions of building block concepts that will be used to allow the receiver system to grow within the framework of the Satellite Control Facility in order to meet future requirements of space programs.

SECTION 2
DESIGN REQUIREMENTS

2.1 GENERAL REQUIREMENTS

Tracking station design will change greatly during the period 1963 to 1970. An evolution of tracking stations will be required to meet an increasing number of Air Force Programs and an increasing number of orbiting vehicles. In time, it will become impractical to use the current system of individual equipment in support of individual programs. Equipment sharing between programs and vehicles will be a necessity by 1970, and the concept of the multipurpose station will, by then, be commonplace.

The multipurpose station must have the capability of switching antennas, receivers, digital transmission, and data processing rapidly as the program requirements change and as different types of space vehicles appear over the tracking station. Central control will become even more critical than it is at present, because station equipment will have to be changed remotely and automatically within a matter of minutes.

In the natural evolution of central control, remote control will be initiated by the operator switching functions on a central control panel. Later, the space vehicle's orbits will be programmed into a computer and the computer will operate the station. At this time, the role of the operator will change from one of equipment control to one of monitor of computer control.

The requirements discussed above will impose high reliability on all equipment within the system. Down-time of more than a few minutes cannot be tolerated and, therefore, failure reporting and isolation systems will be required to provide quick reaction and correction in the event of a failure.

The multipurpose receiver system must be designed to meet the evolution of the ground stations and the demands that will be placed on the entire station complex. But, because parameters will change with time, the receiver system design must incorporate functions and techniques that will be applicable to the many classes and types of orbiting spacecraft that will be operational in the future. In short, the multipurpose receiver must be designed to achieve maximum potential and to avoid design elements that could later make the receiver system obsolete.

This may be the first time that the techniques for an advanced multipurpose receiver have been investigated. Because of this, this report contains many concepts, techniques, and ideas for solving receiver design problems which are not fully proven and which will require evaluation and more investigation.

2.1.1 Basic Requirements Studied

The basic requirements that have been studied are for a receiver using solid state design that will satisfy the following criteria:

a. Can be tuned from 100 mc to 10 Gc

b. Contains multiple functions of operation

c. Has bandwidths of 1 CPS to 30 mc, and higher

d. Has high availability and reliability

e. Can be easily maintained

f. Can be remotely controlled.

g. Uses advanced packaging techniques

h. Uses advanced or new electrical techniques.

The final receiver design will include all of the above.

2.2 DESIGN REQUIREMENTS

2.2.1 Receiver Tuning

The receiver can be tuned from 100 mc to 10 Gc. The techniques employed can be used to extend the tuning range to frequency bands that are both higher and lower than the 100 mc to 10 Gc values. This tuning capability has been accomplished by using six r-f heads, an array of harmonic generators, and a unique frequency synthesizer referenced to a STALO.

The r-f mixers proposed for the final receiver design are conventional. However, as discussed in Section 5 of this report, tunnel diode mixers have great potential and require extremely low local oscillator power. They must be investigated further during the hardware development program, however, before the final design can be selected.

The harmonic generator design as proposed for the receiver is certainly a challenge. At present, the bandwidth of a multiplier chain must be increased for optimum use in the multipurpose receiver. An investigation of the harmonic generator problem in connection with tunnel diode mixer applications must be completed before final design can be determined.

There is great promise that the problems in design can be solved. The harmonic generators are the best way to solve the tuning problem when an ultra-stable Local Oscillator (LO) is needed. The completely solid state design has growth potential.

The solution to the tuning problem by using the recommended frequency synthesizer is certainly a remarkable one. The basic design uses conventional circuits and produces tuning in discrete steps at any desired frequency. As newer components become available, the synthesizer has growth potential to tune to 10 Gc directly at its output. At present, the synthesizer can easily be extended to 1000 mc.

The difficulty in synthesizer design envolves providing an easy to operate programmer and display of the received signal frequency (not the synthesizer frequency). The problem was solved during the study by using a reliable mechanical digital computer. This problem, however, should be investigated still further before final design is selected.

2.2.2 Multiple Functions of Operation

Multiple functions include standard A-M and F-M detection, feedback F-M detection, and phase lock. (These are available with front panel controls.) Certainly, these functions are necessary for the true multipurpose receiver.

2.2.3 Wide- and Narrow-bandwidths

The multipurpose receiver has r-f bandwidths from 1 cps to 30 mc and higher. The low bandwidths are accomplished by using phase-lock frequency tracking filters. The wide bandwidths are accomplished by using frequency lock or an F-M feedback discriminator.

The principles of phase lock are well known. The limitations for using very narrow-bandwidths (less than 10 cps) have been those of suitable component development for transmitter and voltage controlled oscillators. The greatest concern has been for sufficient oscillator stability. Until more stable oscillators can be developed suitable for space vehicles, the lowest practical bandwidth for r-f above 1000 mc will be about 1 cps and this, at present, is difficult to achieve at the higher r-f (2 to 10 Gc.)

The concept of F-M feedback has been known for sometime, but, until the advent of the communication satellite, it did not have an application except possibly for tropo-scatter communication systems. The development of the concepts into practical hardware is a current development. It has great advantage for reducing the F-M threshold and must become part of the multipurpose receiver. Philco, at present, is investigating the development of suitable techniques, but circuit embodiment cannot presently be termed state-of-the-art. This is only a temporary status. There will therefore be a requirement for development in this area in the receiver's design.

2.2.4 Availability, Reliability, and Maintainability

The goals placed upon the receiver design study were an availability of 0.9999 and MTR of 0.1 hour. This results in a MTBF of 1000 hours. These goals were set because it is recognized that equipment, in order to be used frequently, must have a high availability and quick restoration in a case of failure. Further, it is desirable that the receiver not be the limiting factor in a receiving system of 1970. The design must be ahead of present day reliability of associated equipment such as the antenna system.

A maintainability analysis has shown that the mean-time-to-restore has been estimated to be 13.5 minutes rather than 6 minutes. Since the reliability estimates are approximately 2000 hours (mean-time-between-repairs) or greater, the availability of 0.9999 is still maintained. For a MTBR of 1000 hours or greater, an availability of 0.99975 would result.

Ways to reduce the MTR of 13.5 minutes to 6 minutes can still be investigated during the receiver development. However, the procedures for restoring the operation must be followed in a very efficient manner (in time duration) in order to meet the 6-minute requirement.

To accomplish the MTR of 6 to 13.5 minutes will require an automatic failure reporting and fault isolation system. And the reliability of this system will need to excel the reliability of the receiver. Such a system has been included in the design.

2.2.5 Remote Control

The importance of remote control will increase as time goes by. It must be a necessary ingredient in the receiver design to accomplish multiple satellite tracking with short turn around time. Capability of remote control is designed into the basic receiver configuration.

2.2.6 Advanced Physical Design

In the past large ground receiver systems have consumed from one to three racks of equipment. In the case of the multipurpose receiver, additional functions of tunable frequency synthesizer, failure reporting and isolation system, and multiple band R-F heads are included in one rack of equipment. To accomplish this, a change in physical design was necessary.

To decrease the physical size of receiver equipment, miniature (and subminiature) packaging techniques were investigated during the study. Many of the packaging techniques investigated are in use in digital systems. Others claim to have been used up to 150 mc. The chief concern in the receiver design is to apply them to I-F amplifiers. The layout of the basic receiver (synthesizer, failure reporting and isolation system, monopulse receiver) used miniature techniques.

The recommended design is still in the concept and predevelopment stage concerning receiver applications. The basic concept of miniaturization will require development of I-F amplifiers (5 mc and 69 mc) in particular. This will be necessary in the early development of the receiver.

For ground receivers, miniaturization introduces an operational problem. It is a problem to place all the operator controls on the front panel within the same vertical rack space used by the modules behind the panel. The front panel recommended by this study is slightly smaller than normal. This is not a problem if the main application of the receiver is in a remote control station operation.

The front panel problem will be forever present if many operating controls are necessary. One solution to the problem is to combine many functions and place several potentiometers in tandem using one front panel control.

The situation during the development stages will require further investigation.

2.2.7 Advanced Electrical Design

These are techniques being developed at Philco WDL that can be used in the multipurpose receiver design. Their basic function is to provide a continuously variable I-F bandwidth and to change the I-F center frequency using front panel controls and without plug-in units. Section 8 contains a discussion of I-F requirements.

The receiver system must be designed to be universal in operation, oriented to performance and to the user. Consider first the question of performance. (See Fig. 2-1).

In order to have a true multipurpose receiver system, it should have continuous tuning from 100 mc to 10 Gc, or at least within the space frequency bands. Further, the stability of the local oscillator should be equal to the best crystal oscillator that can be made. This tuning operation can be obtained in discrete steps using a frequency synthesizer. The resolution of the steps could be any prescribed value, for example, 1×10^{-6} of carrier frequency, or 10 kc at 10 Gc. For the receiver to be completely flexible, a frequency synthesizer should be

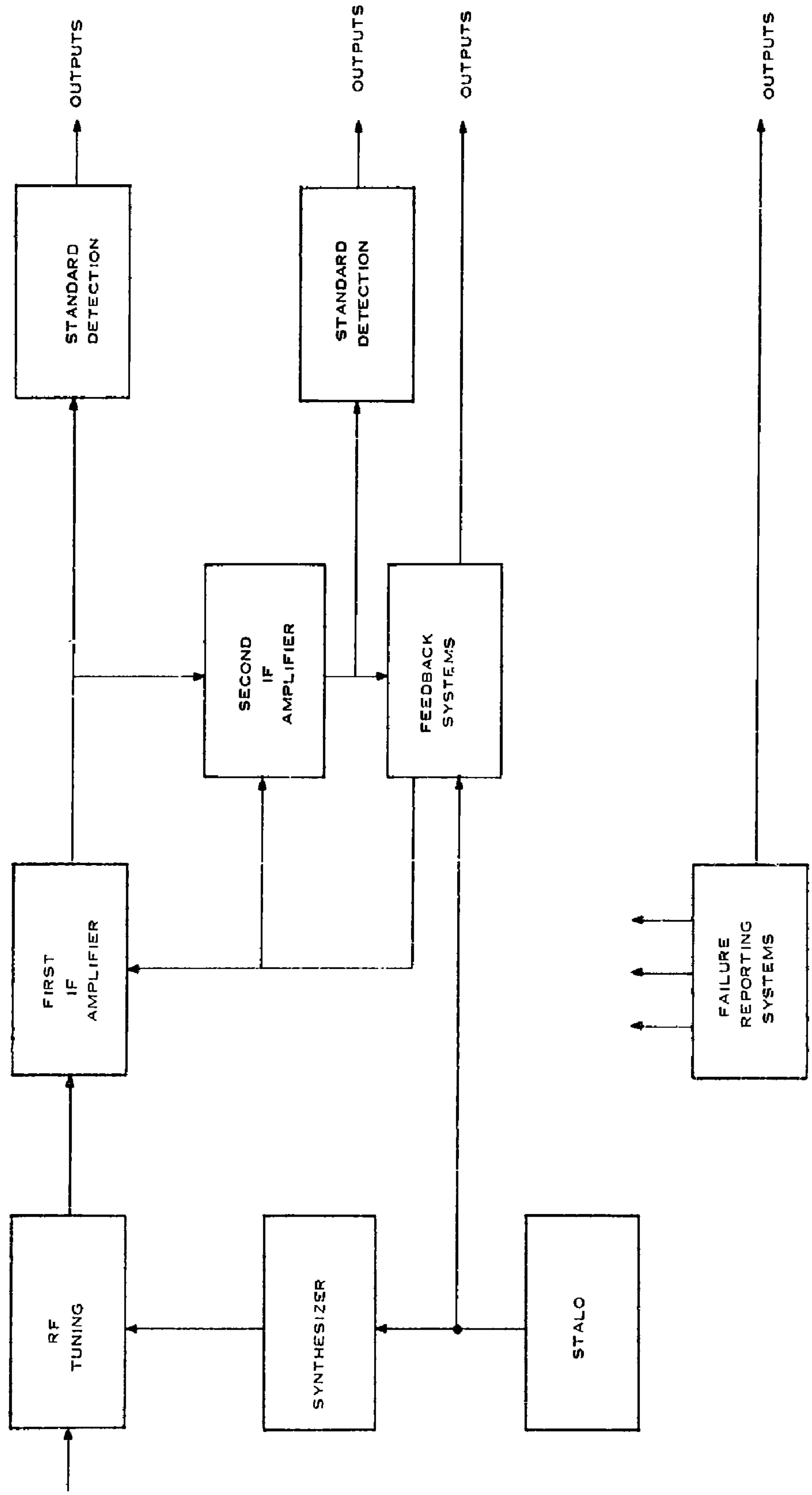


Fig 2.1 Conceptual Physical Diagram of Multipurpose Receiver System

used that is capable of external automatic programming. Additionally, the local oscillator multiplier chain should be capable of accepting external crystal and variable frequency controlled oscillator signals.

It should be noted that the frequency synthesizer and its reference STALO should be the permanent components in the receiver tuning.

The r-f section includes the bandpass filters, mixers, I-F pre-amplifiers, and local oscillator harmonic generators. The true multi-purpose receiver system would not require plug-ins. The receiver must be capable of providing all bands or specific bands required by the customer or user.

Lowest obtainable practical thresholds should be used with June 1962 state-of-the art. This implies the use of frequency and phase lock detection methods.

The space programs of today require r-f bandwidths up to 20 to 30 mc. Future programs in isolated cases will require r-f bandwidths up to 100 mc at higher frequency bands (3 Gc and up). In order to keep I-F bandwidths to a reasonable value (not exceeding 30 mc) bandwidth compression techniques will be used (frequency lock or F-M feedback).

Phase lock narrow bandwidth (1 cps to 3000 cps) frequency tracking filters are needed for doppler frequency tracking and for low level received signals. The filter is adaptable to narrow-band F-M detection for use in space probes or operational systems.

The multipurpose receiver will have need for many I-F and video-bandwidths as it is used for many functions and services. These bandwidths should be changed with continuously variable filters using electrical means. The I-F filters will need to have values from 500 cps to 30 mc.

There will be installations where the r-f tuning unit (filter, mixer, I-F preamplifier and harmonic generators) for each frequency band used may be physically located in the receiver rack or in the antenna reflector or pedestal. The r-f tuning unit must be electrically and physically designed to operate in either installation.

2.2.8 Doppler and Angle Tracking

The receiver system must be capable of being employed in angle and doppler tracking systems. The angle tracking systems must include conventional monopulse (phase or amplitude) and conical scan. Doppler extractors need not be part of the receiver.

2.3 SUMMARY

The concepts governing design of the multipurpose receiver, as described in this report, will push the state-of-the-art into the next receiver stage of development. The multipurpose receiver discussed can operate within most space programs and can fulfill nearly all program requirements.

The receiver will, however, require new development efforts as discussed in Section 9. But, on a production basis after proven design, costs should be minimized for receivers in present and future space-vehicle tracking stations.

SECTION 3

PERFORMANCE SPECIFICATIONS

3.1 GENERAL

This Section contains the performance requirements for the multipurpose receiver as determined from the mission operation, program requirements, general performance and operating characteristics.

3.2 INPUT SIGNAL CHARACTERISTICS

3.2.1 Type of Modulation

- Wide-band frequency modulation (high index)
- Narrow-band frequency modulation (low index)
- Narrow-band phase modulation (low index)
- Amplitude modulation
- Continuous carrier (CW). (Doppler)

3.2.2 Frequency Range of Carrier Frequency

100 mc to 10 Gc.

3.2.3 R-F Bandwidth

- One per cent of r-f carrier frequency or 30 mc (whichever is smaller
- In the frequency band 4 Gc to 10 Gc, bandwidths up to 100 mc can be received when utilizing FM feedback in the detection scheme.

3.2.4 Dynamic Range of Signal

The dynamic range is -60 dbm to -184 dbm. (The -184 dbm is a design goal when using a 1 cps bandwidth and a preamplifier noise temperature of 30 degrees Kelvin.)

3.3 PERFORMANCE SPECIFICATIONS AND REQUIREMENTS

3.3.1 Receiver Tuning Unit

Frequency Range of Carrier Frequency

100 mc to 10 Gc

Tuning

Full coverage is desired between 100 mc to 10 Gc, but it is not a requirement. Continuous tuning using a voltage controlled oscillator for vernier tuning and a resolution of 1×10^{-6} of carrier frequency using a frequency synthesizer is required in all space frequency bands.

The space frequency bands include:

- 136 to 137 mc
- 225 to 260 mc
- 375 to 401 mc
- 1.365 to 1.660 Gc
- 1.7 to 1.85 Gc
- 2.2 to 2.45 Gc
- 4.0 to 4.2 Gc
- 8.4 to 8.5 Gc.

R-F Input Impedance

50-ohms nominal for coaxial cable, VSWR less than 1.1 for wave guide.

Noise Figure

10-db maximum at 10 Gc including effects of bandpass filter in front of mixer without the use of a preamplifier. Using a preamplifier (not part of this receiver) effective excess noise figure temperature of 30-degrees Kelvin may be used.

Preamplifier Types *

The receiver must be designed to operate with preamplifier types which include maser, parametric, parametric beam, tunnel diode, transistor, ceramic tube, and traveling wave tube.

I-F Rejection

40-db minimum.

Image Frequency Rejection

40-db minimum.

Dynamic Range of Input Signal

-60 dbm to threshold with the minimum threshold of -184 dbm being a design goal.

I-F Preamplifier

a. Bandpass Characteristics.

R-F Frequency Band	Center Frequency	Bandwidth	Noise Figure
100 to 500 mc	21 mc	7.0 mc	1.5 db
500 mc to 10 Gc	69 mc	45 mc	2.0 db

b. Power Amplification or Gain:
25 db minimum.

c. Impedance
   (1) Input: Designed to match mixer for minimum noise figure.
   (2) Output: 50 ohms.

* Not part of this receiver.

First Mixer Conversion Loss

Not more than 6 db.

Mixer Bandwidth

- Octave bandwidth
- Greater than 45 mc at output.

3.3.2 Frequency Synthesizer and Local Oscillators

First Local Oscillator Tuning Range

The local oscillator frequency shall equal the signal r-f carrier frequency minus the I-F amplifier frequency. Continuous tuning using a voltage controlled oscillator for vernier tuning and discrete tuning using a frequency synthesizer are required within the space frequency bands. In some cases VCO tuning solely will be utilized.

Coupled or Conduction of Local Oscillator Signal

- -100 dbm at input to 5 mc I-F amplifier at frequencies within its passband (4 mc to 6 mc)
- -165 dbm at input to first I-F amplifier at frequencies within the I-F passband (design goal).

Available Power to Mixer

10-milliwatts minimum for 3 mixers.

Preselector Output Impedance

50-ohms nominal.

Local Oscillator Types

The receiver shall be designed to use the following type local oscillators:

a. Frequency Synthesizer
b. VCO
c. VCO plus harmonic generator
d. External Input (10 mw power at 50-ohms impedance).

Frequency Synthesizer

a. Inputs:

(1) Stable Local Oscillator (STALO)

(2) Digital input from digital computer or other controlling source (STALO reference)

(3) Frequency hopping signal using code generator and/or code matrix (STALO reference).

b. Output:

(1) Local oscillator signal to first mixer (10 mw in 50 ohms - synthesizer includes design of necessary harmonic generators).

c. Spurious Response:

(1) The output signal must have spurious response 60 db or more (design goal) down from the LO output signal level.

(2) Coupled or conducted signals between 4 mc to 6 mc must be less than -100 dbm at the input to the 5 mc I-F amplifier.

(3) Coupled or conducted signals within the first I-F amplifier passband must be less than -165 dbm (design goal).

d. Operator Control and Display:

(1) The synthesizer must generate the desire frequency by simple manipulation.

(2) No retuning or adjustment of controls should be allowed or necessary. The output frequency should require no calibration or any additional equipment to verify its frequency.

(3) The frequency selected should be directly readable on the manual controls and local display.

(4) The estimated received signal frequency shall be displayed in decimal digits.

(5) There must be provision for a remote display.

e. Resolution:

The resolution shall be 1×10^{-6} of the carrier frequency. For example,

Carrier Frequency	Resolution
100 mc	100 cps
1000 mc	1000 cps
10 Gc	10 kc

The resolution shall be easily extendable.

f. Frequency Stability:

The output signal characteristics shall be equal to the reference driving signal (STALO) as far as short and long term instabilities are concerned.

Stable Local Oscillator (STALO)

Output Frequency

1.0 mc.

Output Impedance

50 ohms

Output Level

20 mw minimum.

Frequency Stability

The following stabilities are required for receiver phase-lock operation at 10 Gc in 1 cps noise bandwidth:

- 1×10^{-11} per second peak (design goal)
- 3×10^{-12} rms (design goal)
- 5×10^{-10} per day peak
- 1×10^{-8} per month peak.

(The best that may be achievable by June 1962 is 4×10^{-11} per second peak and using a 1 cps noise bandwidth at 4 Gc with a crystal type oscillator.)

Spurious Response

- o Noise - 80 db down minimum.
- o Harmonic Distortion - 90 db down minimum.

First I-F Amplifier

Noise Figure

4 db maximum.

Bandpass Characteristics

R-F Frequency Band	I-F Center Frequency	I-F Bandwidth	Effective Max. I-F Bandwidth*	Bandwidth Control
100 to 500 mc	21 mc	200 kc to 7 mc	5 mc	continuous or discrete
500 mc to 10 Gc	69 mc	1.0 mc to 45 mc	30 mc	continuous or discrete

* Includes effect of I-F preamplifier bandwidth.

Input and Output Impedance

50 ohms.

First I-F Amplifier Gain

- 90 db using single conversion
- 35 db using double conversion (+25 db in I-F preamplifier).

AGC Attenuation

- 90 db using single conversion
- 30 db using double conversion

Second Mixer

Noise Figure

6 db maximum.

Conversion Gain

6 db minimum

Impedance

a. Input:

(1) Greater than 500 ohms (signal input)
(2) 50 ohms oscillator input.

b. Output:

(1) 50 ohms.

Second I-F Amplifier

Noise Figure

5 db maximum.

Bandpass Characteristics

- Center Frequency: 5 mc
- Bandwidth: 500 cps to 1 mc
- Bandwidth Control: Continuous electrically or electronically tuned or varied in discrete steps using plug-in filters.

Second I-F Amplifier Gain

Nominal 120 db.

AGC Attenuation

120 db

Detection Methods

Amplitude Modulation

a. Outputs:

(1) First I-F amplifier after envelope detector
(2) Second I-F amplifier after envelope detector
(3) Phase lock amplitude detector.

b. Detector Bandwidths:

(1) First I-F amplifier:

- 30 mc I-F Bandwidth
- 0 to 10 mc video in steps of .03, .1, .3, 1, 3, 10 mc.

(2) Second I-F amplifier:

- 1 mc I-F Bandwidth
- 0 - 500 kc video in steps of 1, 3, 10, 30, 100, 500 kc.

(3) Phase Lock Amplitude Detector

- 1 mc I-F Bandwidth
- 0 to 500 kc video in steps of 1, 3, 10, 30, 100, 500 kc.

Frequency Modulation (without Feedback Detection)

a. Outputs:

(1) First I-F amplifier before discriminator
(2) Second I-F amplifier before discriminator.

b. Detector Bandwidths:

(1) First I-F Amplifier

- 30 mc I-F
- 0 to 10 mc video in steps of .03, .1, .3, 1, 3, 10 mc.

(2) Second I-F Amplifier

- 1 mc I-F
- 0 to 500 kc video in steps of 1, 3, 10, 30 100, 500 kc.

Frequency Modulation with Feedback

a. Outputs:

(1) First I-F amplifier using discriminator

(2) Second I-F amplifier using discriminator.

b. Bandwidths:

I-F Amp.	Maximum R-F Bandwidth	Maximum I-F Bandwidth After Compression	Video ** Bandwidth
First	30 mc to 100 mc*	20 mc	10 mc
Second	30 mc	1 mc	500 kc

* The R-F bandwidths above 30 mc are available in the frequency bands 4.0 to 4.25 Gc and 8.4 to 8.5 Gc only (using a special R-F head design).

** Available in steps identical to FM without feedback.

c. Voltage Controlled Oscillator Frequency Deviation

(1) First Mixer

Multiplier	Deviation
256	$\pm$ 50 mc
128	$\pm$ 35 mc
64	$\pm$ 20 mc
32	$\pm$ 10 mc
16	$\pm$ 5 mc

(2) Second Mixer

$\pm$ 6 mc.

d. Feedback Factor:

3 db to 27 db in 3-db steps.

Automatic Frequency Control

a. Bandwidth:

(1) First Mixer

100, 300, 1000, 3000 cps.

(2) Second Mixer

30, 100, 300, 1000 cps.

Phase Lock Detection

a. Output:

Second I-F amplifier using phase detector.

b. Modulation:

(1) Narrow-band frequency modulation (modulation index less than one)

(2) Narrow-band phase modulation (modulation index less than one)

(3) Continuous carrier (CW)

c. Bandwidth:

(1) R-F and I-F: 1 mc

(2) Video: 0 to 500 kc

(3) Frequency tracking of continuous carrier:

1 cps to 3.0 kc in steps.

3.3.8 Phase Lock Operation

Noise Bandwidth ($2B_L$)

1 cps to 3.0 kc (available in steps.)

Mode of Operation

a. Wide-band:

$2B_L$ equals 100 cps to 3 kc, 100, 300, 1000, 3000 cps

b. Narrow-band:

$2B_L$ equals 1 cps to 100 cps, 1, 3, 10, 30, 100 cps.

c. Operation:

Mode	Tracking Range*	Lock Point
Narrow-band	5×10^{-5} of f_o	First mixer
Wide-band	500 kc	Second mixer

* F_o equals r-f Carrier Frequency.

d. Allowable Frequency Deviation:

(1) First Mixer

Multiplier	Deviation	
	Course	Fine
256	± 100 kc	± 10 kc
128	± 70 kc	± 7 kc
64	± 40 kc	± 4 kc
32	± 20 kc	± 2 kc
16	± 10 kc	± 1 kc

(2) Second Mixer

Deviation	
Course	Fine
± 500 kc	± 50 kc

<u>Acquisition Parameter</u>

a. Noise Bandwidth:

1, 3, 10, 30, 100, 300, 1000 cps

b. Sweep Width:

1 to 10 cps

1 to 100 cps

1 to 1000 cps

1 to 10 kc

1 to 100 kc

c. Sweep Period:

0.1 to 1 second

0.1 to 10 seconds

0.1 to 100 seconds

Voltage Controlled Oscillators (VCO)

Mode	Linearity (variation in slope)	Frequency Stability	
		Long Term (peak per day)	Short Term (peak per second)
Narrow-band	± 2%	5×10^{-10}	* 4×10^{-11}
Wide-band	± 5%	1×10^{-5}	1×10^{-6}

* This is a 1-cps noise bandwidth at 2 Gc. Smaller bandwidths and higher input r-f frequencies will require better stability.

3.3.9 Phase Detector and Discriminators

Linearity

The slope over the operating bandwidths shall not vary more than ± 1 per cent.

3.3.10 Limiters

Limiting Level for Phase Lock

There shall be sufficient gain in front of the limiter to permit the limiter to limit without signal, and signal without noise when using any preamplifier (and no pre-amplifier).

Bandwidth

The bandwidth of the limiter must exceed the largest I-F filter bandwidth and be sufficiently low to attenuate the harmonics of all intermediate frequencies and, particularly, the second.

3.3.11 Automatic Gain Control (AGC)

Modes of Operation

a. Manual (MGC)

b. Uncorrelated:

(1) First I-F Output
(2) Second I-F Output.

c. Correlated.

Dynamic Range

a. Manual: 124 db.

b. Uncorrelated:

(1) First I-F Output

- 90-db single conversion
- 30-db double conversion

(2) Second I-F Output: 124 db.

(3) Correlated: 124 db.

Amplitude Control
The AGC shall maintain the output signal level at its nominal value within a maximum variation of 3-db over the entire dynamic range of the receiver.

Function Controls
The slope, delay, and slope shape shall be controllable and outputs shall be provided to a standard receiver and a three-channel monopulse receiver.

Noise Bandwidth

The noise bandwidth shall be adjustable in the following steps: 0.3, 1, 3, 10, 30, 100 cps.

3.3.12 Video Amplifier

Gain

0 to 10.

Frequency Response

Adjustable from d-c to 10 mc in steps:

I-F Bandwidth, 1 mc: 1, 3, 10, 30, 100, 500 kc

I-F Bandwidth, 30 mc: 3.03, 0.1, 0.3, 1, 3, 10 mc

Output

- Level: ± 0.5 volt peak
- Impedance: 100 ohms
- Load: 100 ohms minimum.

3.3.13 Monopulse Operation

Cross Talk (leakage)

The cross talk between channels shall be less than -40 db.

Null Noise Level

The null noise generated within the receiver in addition to noise figure type noise shall be 35-db down from the sum signal power level.

Relative Phase Shift

The random relative phase shift before the phase detectors between the reference or sum channel and either error channel should not exceed 10 degrees referenced from the receiver input terminals.

3.4 RECEIVER OUTPUTS

3.4.1 Detected Signals

Amplitude Modulation

- Single conversion envelope detection
- Double conversion envelope detection
- Double conversion linear detection (phase lock).

Frequency Modulation

a. Single Conversion:

(1) Feedback
(2) No Feedback

b. Double Conversion:

(1) Feedback
(2) No Feedback

Phase Modulation
Double conversion linear detection.

3.4.2 Oscillator Outputs

- First local oscillator
- Second local oscillator
- Frequency synthesizer
- Stable local oscillator
- Voltage controlled oscillators.

3.4.3 I-F Amplifier Outputs

- First I-F amplifier
- Second I-F amplifier.

3.4.4 AGC Outputs

- First I-F amplifier uncorrelated
- Second I-F amplifier uncorrelated
- Second I-F amplifier correlated.

3.5 ENVIRONMENTAL SPECIFICATIONS

3.5.1 Operating Environment

Temperature

The equipment shall withstand the following temperatures:

a. -7 to +43 degrees C (Operate at rated performance)

b. -20 to +54 degrees C. (Operate with no damage at reduced performance).

Humidity

The equipment shall be capable of operating at rated performance at relative humidities from 10 to 98 per cent at temperatures from -7 to 43 degrees C.

Barometric Pressure

The equipment shall be capable of operating at rated performance in barometric pressures of 610 MM to 775 MM of mercury.

Other Atmospheric Conditions

The equipment shall perform as specified when operated in any probable combination of the following as may be encountered in a building or van:

- Sand
- Dust
- Smoke
- Ozone
- Salt Atmosphere

3.5.2 Non-Operating Environment

Non-Operating Environment (Equipment Packaged)

Equipment shall be packaged in accordance with Specification MIL-P-116C and shall withstand the most rigorous environmental conditions specified herein. In addition, equipment shall withstand shock and vibration encountered during transportation.

Non-Operating Environment (Equipment Unpackaged)

a. Temperature:

The equipment shall be capable of satisfactory operation after being exposed to the following temperature conditions:

(1) Lower Limit: $-54^{\circ}C$ for a period of eight hours.

(2) Upper Limit: $+71^{\circ}C$ which includes the effects of solar radiation for a period of four hours per day.

b. Humidity:

Without degradation of performance, the equipment shall withstand relative humidities up to 98 per cent at temperatures up to $50^{\circ}C$.

c. Shock:

Without degradation of performance, the equipment shall withstand shocks received by tilting the equipment to an angle of 30° or six inches (whichever limit is reached first) and allowing it to fall freely to a flat solid surface. The equipment shall be subjected to a minimum of four such falls, located 90° apart with respect to the base of the equipment.

d. Vibration:

Without degradation of performance, the equipment shall be capable of withstanding (along each of three mutually perpendicular axes) sinusoidal vibration as encountered during handling incident to use of the equipment. The test shall be performed in three cyclic sweeps (constant octave) with a sweep duration of fifteen minutes. The limits of the test shall be as follows:

Frequency	Double Amplitude or Vibration Acceleration
10 cps to 27.5 cps	1.3 G
27.5 cps to 52 cps	0.036 inch
52 cps to fp	5.0 G

SECTION 4

RECEIVER SYSTEM DESIGN PLAN

4.1 GENERAL

The basic design of the receiver system must meet current and future customer requirements. A master plan (based on considerations that affect design and required receiver system functions and features) has been established and is presented in this Section.

4.2 CONSIDERATIONS THAT AFFECT DESIGN

It must be recognized that the receiver system will be placed in an environment where the following conditions will probably prevail.

4.2.1 Automatic Operation

The station will be operated in an automatic manner from a central control point and/or through a digital computer.

4.2.2 Multifunction

The receiver system will be used on more than one program with different space vehicles and will therefore need to perform many different functions.

4.2.3 Quick Reaction

Turn around time will be short and the receiver system must perform its functional changes quickly and automatically.

4.2.4 High Reliability/Availability

The availability of the receiver must be very high in order to meet the above conditions. The availability and reliability must exceed the requirements of present day receivers.

4.2.5 Automatic Failure Reporting

To accomplish high reliability and availability, an automatic failure reporting and fault isolation system must be used to restore operation quickly in the event of a malfunction.

4.2.6 Remote Control

To provide automatic operation, quick reaction time, and automatic failure reporting, remote control will be required for operational control within the time allowed and with a minimum of operator attendance.

4.2.7 High Maintainability

Minimum rack space and high maintainability should be included in the physical design of the receiver.

The majority of the above requirements can be met with one basic receiver system configuration.

4.3 RECEIVER FUNCTIONS AND FEATURES

The functions that may have to be switched* within the turn around time allowed are listed below:

a. R-F bands, 100 mc to 10 Gc.

b. L-O frequency within an r-f band

c. Change receiver detection between:

   (1) Phase lock for doppler

   (2) FMFB or frequency lock for wide-band signals.

   (3) Conventional am and FM.

d. Receiver bandwidths

e. Monopulse to conical scan angle tracking.

* All of the above functions may or may not be needed within a single receiver system.

From a physical configuration viewpoint, it is easy to separate the following functions into separate chassis drawers.

a. R-f head
b. Harmonic generators
c. Frequency synthesizer
d. STALO
e. Basic Receiver:
   (1) Right chasis, standard receiver
   (2) Left chassis, feedback systems
f. Failure reporting and isolation system
g. Power supplies and a-c control panel
h. Monopulse error channels.

It should be possible, by deleting equipment or by adding substitutions, to accomplish the following:

a. Supply r-f heads from one up to six to cover a single frequency band or all bands from 100 mc to 10 Gc

b. Supply harmonic generator chains from one to eight to meet the requirements of (a) above

c. The advanced frequency synthesizer could be replaced with a single synthesizer supplying a single L-0 frequency

d. The STALO could be replaced with an inexpensive, less stable, reference oscillator

e. The "basic" receiver could be supplied without phase and frequency lock feedback systems

f. The failure reporting and isolation system can be omitted

g. The remote control functions must be designed into the receiver to meet future needs because remote control can not be simply added

h. The monopulse error channels can be easily added or omitted.

The receiver system can be originally designed as discussed in the Physical Design Section (Section 15) or it can have a more conventional design which will consume additional rack space. The conventional design would be a backward step especially when considering the date of design completion and, therefore is not recommended.

4.4 MASTER PLAN

The master plan for the design and of the multipurpose receiver system will accommodate the recommended design and the capability for the alternatives listed in Paragraph 4.3

The recommended design plan includes the following:

- R-F heads as necessary
- Harmonic generators to complete a single r-f band or as necessary
- The frequency synthesizer with 1×10^{-6} tunable resolution
- The STALO
- Basic receiver including frequency and phase lock
- Failure reporting and isolation system
- Remote control potential
- Advanced miniature physical design.

The physical and electrical designs for the receiver system (as studied) will include a choice for the alternatives stated above with "built-in" remote control. This will give the customer complete latitude in obtaining what he requires in an advanced design receiver system with great potential in adaptability and versatility to meet the majority of his present and future needs.

SECTION 5
DESCRIPTION OF R-F HEAD

5.1 FRONT END CONFIGURATIONS

The part of the receiver defined as the Front End (see Fig. 5-1) consists of the following:

a. R-F Amplifier (preamplifier)
b. Preslector (Filter)
c. Mixer
d. I-F Preamplifier
e. Local Oscillator

The present study program does not include the r-f amplifier, so, for the purpose of this report, the input to the multipurpose receiver is at the preselector. The impedance at this point is the standard 50 ohms so that a coaxial cable can be used for connection to the antenna or the r-f amplifier (if used).

In Fig. 5-1, the name on each block adequately describes what it represents, with the exception of the Local Oscillator (LO). In its simplest form, the LO can be a crystal oscillator followed by amplifiers and frequency multipliers, or it can be a simple variable frequency oscillator. Oscillators of these two types will not be integral parts of the receiver; but using a coaxial connector permits their use by customers who want this type of operation. In most cases the local oscillator will consist of a frequency synthesizer with amplifiers and a string of harmonic generators as described in Section 6.

The receiver front end may be antenna or rack mounted, depending upon application conditions, or it may be divided between these two locations. (Fig. 5-2 contains three possible antenna equipment configurations.)

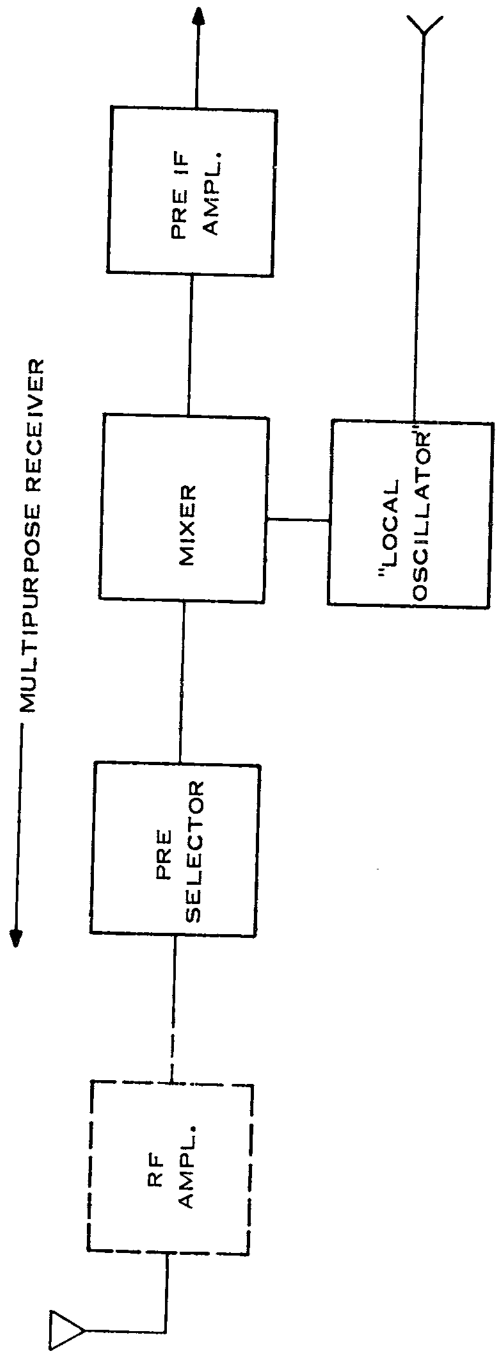


Fig. 5-1 Receiver Front-End

Alternative I, in Fig. 5-2 (the whole front end "downstairs") is possible only when the feeder losses are small. In this case, the feeder losses will add directly to the receiver noise figure, and thus decrease the sensitivity. Generally speaking, this alternative will be used only for short feeders; for instance where the equipment is mounted in a Van.

In Alternative II, of Fig. 5-2 an r-f amplifier is mounted on the antenna. Even with fairly high feeder losses and main receiver noise figure, the overall noise figure will be only slightly higher than that of the r-f amplifier itself. A practical example will show this, and may be seen in the following example:

F_1 = RF Amplifier Noise Fig. 5 db

G_1 = RF Amplifier gain 30 db

L = Feeder loss 6 db

F_2 = Main Receiver Noise Fig. 10 db

The overall noise figure is:

$$F = F_1 + \frac{L_2F_2 - 1}{G_1} = 3.16 + \frac{4 \times 10 - 1}{1000} = 3.199 \text{ or } 5.045 \text{ db} \qquad (5\text{-}1)$$

The degradation of the r-f amplifier noise figure is very slight.

An arrangement according to Alternative II would be particularly simple in cases where the tuning range is not too wide. In the 2.2 to 2.45 kmc range, the r-f amplifier would have a fixed tuned filter, and all the tuning within the range would be performed on the rack mounted receiver.

Another possible arrangement is shown under Alternative III. Here, the whole front end is mounted on the antenna. The signal is fed down after having been amplified by a low noise I-F preamplifier. The gain in the antenna mounted equipment is made high enough to "swamp" even high

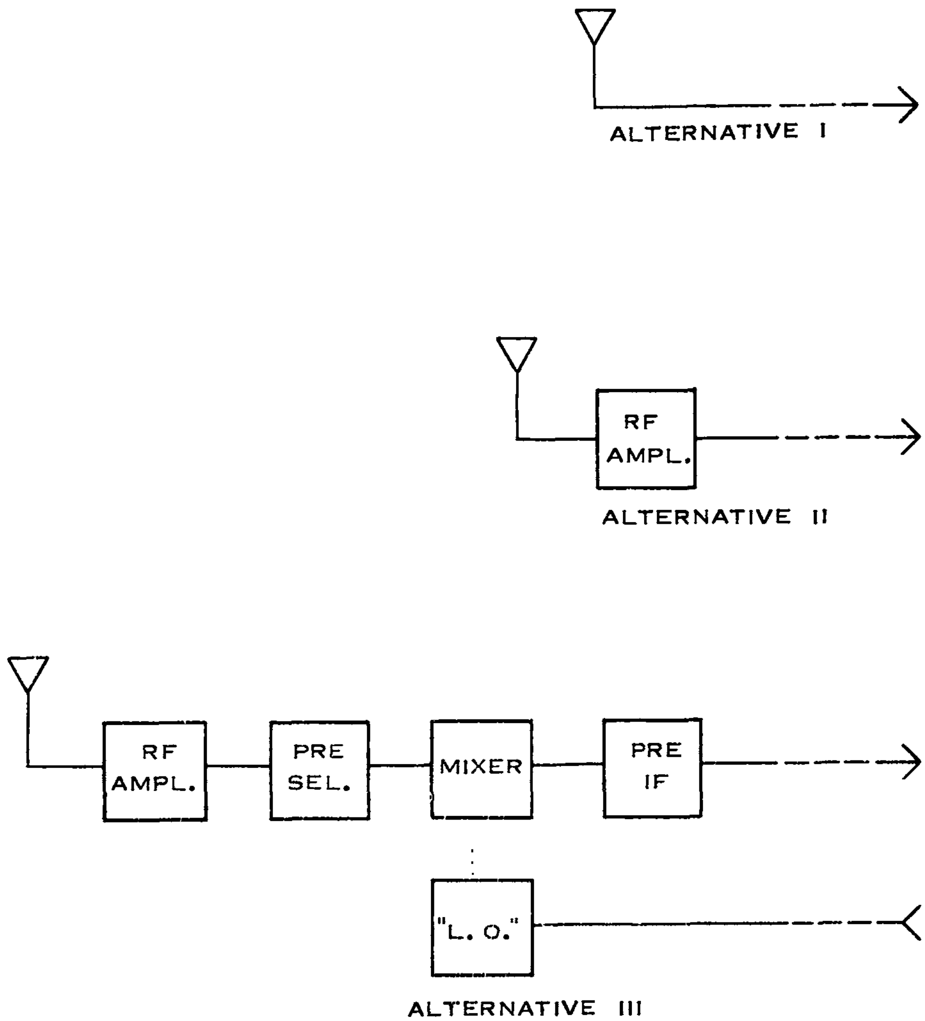


Fig 5-2 Antenna Equipment Configurations

feeder losses. This arrangement has a number of drawbacks. Maintainability is very poor, and this critical part of the receiver will be subjected to the worst environmental conditions.

The conclusion that can be drawn from these considerations is that Alternative II should be used wherever possible. It represents the best compromise considering sensitivity, reliability, and maintainability.

5.2 PRESELECTORS

5.2.1 Performance Requirements

The preselector performs several functions such as band selection, IF and image suppression, and noise rejection. The preselector must prevent strong signals outside the passband from overloading the mixer and creating cross-modulation products from appearing at the intermediate frequency. For space communication systems, receiver antennas are highly directional, hence, 40-db of image rejection is considered adequate.

The r-f preselector bandwidth must be large enough so that it does not appreciably cut into the I-F bandwidth, or degradation of noise figure will result. The insertion loss must be less than 2 db because it adds directly to the noise figure at the mixer input. The tuning range of each preselector should be made as wide as possible so that the number of preselectors needed to cover the bands in the range of 100 mc to 10 Gc are kept low. The minimum tuning range is 10 percent of operating frequency. The preselectors should consist of several resonant sections. Butterworth configuration is preferred because it produces no reflection loss in the passband. Frequency calibration should be accurate to within 1/10 of one percent. Tuning should be programmable with a servo.

The input and output impedances should be 50 ohms and the VSWR should not be greater than 1.5.

5.2.2 Bandpass Filter Characteristics

The amplitude/frequency characteristics of a filter with Butterworth pole distribution is given by:

$$A = 10 \log_{10} \left[1 + \left(\frac{2|f - f_c|}{B} \right)^{2N} \right] \qquad |f - f_c| > B \qquad (5\text{-}2)$$

where A = Attenuation at frequency f

f = Frequency

B = Required filter bandwidth at -3 db points

f_c = Center frequency

N = Number of poles or resonant sections

The relationship between dissipation loss and the ratio of loaded Q to unloaded Q is:

$$L = 20 \log_{10} \frac{1}{1 - \frac{Q_L}{Q_U}} \qquad (5\text{-}3)$$

where L = Dissipative loss in db

Q_L = loaded Q

Q_U = unloaded Q

This shows that the dissipative or insertion loss approaches zero as Q_U approaches infinity.

However, Q_U is proportional to the physical size of the resonant cavity. This limits the value of Q_U, hence, governs insertion loss.

5.2.3 Design Considerations

The bandwidth requirements and choice of IF have been determined from the overall receiver design standpoint, and are discussed in Sections 8.1.4 and 8.1.2 respectively. The first IF frequencies and receiver bandwidths are given as follows:

IF	Receiver Bandwidth (-3db)
21 mc	1 mc to 5 mc
69 mc	1 mc to 30 mc

For the consideration of bandwidth shrinkage, the preselector must have a bandwidth greater than the maximum receiver bandwidth. Thus, using equation (5-3) the preselector design requirement can be specified:

IF	=	69 mc
Bandwidth	=	30 mc
(Maximum r-f	=	3 kmc or above)

The number of poles required in the preselector in order to give greater than 40-db rejection at the image IF and its sideband frequencies, is shown in Fig. 5-3.

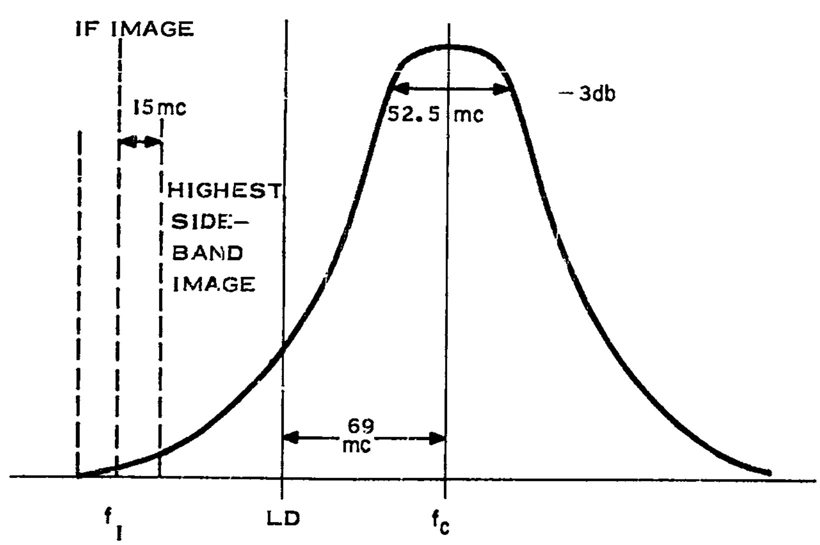


Fig. 5-3

An estimate of the preselector bandwidth is 1.75 x 30 = 52.5 mc. From the Figure:

$$f_1 - f_c = 69 + 69 - 15 \text{ mc} = 123 \text{ mc} \qquad (5\text{-}4)$$

The attenuation for the nearest I-F sideband is then,

$$A = 10 \log_{10} \left[1 + \left(2 \; \frac{123}{52.5} \right)^{2N} \right] \qquad (5\text{-}5)$$

and, when N = 2, A = 26 db
N = 3, A = 40 db

Therefore, for a 40-db image rejection, a 3-pole preselector is required. For a narrow bandwidth, a 2-pole preselector can be used.

From the given receiver bandwidth and IF frequencies for this receiver, and the number of poles required for the preselectors has been determined and is shown in the table below.

Radio Frequency	Intermediate Frequency	Receiver Bandwidth	No. of Poles in Preselector
100 mc - 500 mc	21 mc	RF x 10^{-2}	2
500 mc - 1 Gc	69 mc	RF x 10^{-2}	2
1 Gc - 1.5 Gc	69 mc	RF x 10^{-2}	2
1.5 - 2.0 Gc	69 mc	RF x 10^{-2}	3
2 Gc - 10 Gc	69 mc	RF x 10^{-2} or 30 mc whichever is smaller	3

The advantage of using a greater number of poles is that it gives a steeper skirt response and thus increases image rejection. The disadvantage is that insertion loss increases and tuning is more difficult.

Butterworth passband characteristics should be used so that input VSWR is kept to minimum and reduces reflection loss.

5.2.4 Commercial Products

Commercially available preselectors, with minor modifications, appear to meet the requirements for this receiver. Investigation reveals that the following manufacturers are potential suppliers for the preselectors:

Microlabs Gambos Microwave Inc. Frequency Engineering Labs	0.5 Gc to 10 Gc
Telonic Engineering Corp.	100 mc to 1,000 mc

For frequencies below 250 mc, the preselector can easily be designed in the laboratory using helical resonators or conventional lumped inductors and capacitors.

5.2.5 Tuning Range

Table 5-1 contains suggested preselector and mixer frequency coverages.

5.3 MIXER I-F PREAMPLIFIER

5.3.1 General

The function of the mixer in a superheterodyne receiver is to convert r-f energy to a lower frequency energy where amplification is relatively easy to achieve. Mixers can be either active or passive devices. Active types are used mainly at lower frequencies. They can be used at VHF, but better performance can be obtained by using the active device as an amplifier followed by a crystal mixer. In the UHF and SHF regions, the crystal mixer maintains relatively constant noise figures, while active semi-conductor devices tend to get worse as the frequency is increased. Recent improvements on tunnel diodes indicate

TABLE 5-1

SUGGESTED FREQUENCY COVERAGES

Frequency Range	Mixer Type
100 mc to 260 mc	Octave Mixer
260 mc to 500 mc	Broadband Mixer
500 mc to 600 mc 600 mc to 700 mc 700 mc to 825 mc 825 mc to 1000 mc	500 mc to 1000 mc Broadband Mixer
1.0 Gc to 1.25 Gc 1.25 Gc to 1.5 Gc 1.5 Gc - 2.0 Gc	1.0 Gc to 2.0 Gc Broadband Mixer
2.0 Gc to 2.5 Gc 2.5 Gc to 3.0 Gc 3.0 Gc to 3.5 Gc 3.5 Gc to 4.0 Gc	2.0 Gc to 4.0 Gc Broadband Mixer
4.0 Gc to 5.7 Gc 5.7 Gc to 6.5 Gc	4.0 Gc to 6.5 Gc Broadband Mixer
6.5 Gc to 7.2 Gc 7.2 Gc to 8.0 Gc 8.0 Gc to 9.0 Gc 9.0 Gc to 10.0 Gc	6.5 Gc to 10.0 Gc Broadband Mixer

NOTE: The above units can be supplied by Grombos Microwave Inc.

A tuning accuracy of 0.02 per cent is claimed by the manufacturer.

that a low noise microwave receiver front-end can be designed with a tunnel diode preamplifier and a tunnel diode down converter. A 5.5-db nominal noise figure and 40-mc I-F bandwidth have been achieved by Philco Western Development Laboratories. The converter requires only one microwatt local oscillator power. However, the bandwidth is limited in tunnel diode amplifiers and mixers because of stability requirements. Nevertheless, investigation on tunnel diode mixers and amplifiers should be pursued in the development of the receiver.

5.3.2 Noise Figure of Mixers

There are two configurations of mixers; the single ended and the balanced type. The single ended type is somewhat simpler, yields lower noise figures and is adequate for many applications. In critical cases the balanced mixer has advantages, such as isolation between terminals reduced oscillator noise, requires less oscillator power and is more reliable. The matching to the r-f terminal is also less critical.

The basic noise figure equation for mixer-input receivers is:

$$NF = L_x \, (T_x + N_{IF} - 1)$$

where

NF = overall noise figure

L_x = mixer conversion loss

T_x = mixer noise temp. $= \frac{F_m}{L_x}$ = 1.0 approx.

N_{IF} = IF noise figure

F_m = mixer noise figure

(all numbers in power ratio).

The crystal diode itself determines L_x and T_x and so is the main determining factor of receiver noise figure. Many other factors can degrade the noise figure such as the holder design, input and output matching and image termination, local oscillator drive and isolation.

The conversion loss decreases with increased crystal current, but, at the same time, the noise temperature increases. This results in a somewhat broad optimum of LO drive for minimum noise figure. The optimum crystal current is around 0.6 ma for most crystals but variations from 0.3 to 1.0 ma will usually not affect the noise figure seriously. However, impedances also vary with crystal current and narrower crystal current limits may have to be set once the mixer design is completed. Typical noise figures for mixers utilizing 1N21F or 1N23F crystals, when followed by a 1.5-db I-F amplifier (vacuum tube type) runs around 6 to 7 db. These crystals will cover the entire range from 100 mc to 10 kmc.

5.3.3 LO Power Requirements

Single ended mixers require about 10 mw of available LO power. If less power is used, a closer coupling to the low impedance oscillator is needed, and signal power leaks out this way, greatly increasing the conversion loss and noise figure. Balanced mixers only require 1 to 2 mw, due to inherent LO isolation. For monopulse receivers, about 5 times these LO powers will be needed, or 50 mw for single ended and 10 mw for balanced mixers. For tunnel diode mixers, the required available LO power is only several microwatts.

5.3.4 Impedances

Impedance matching of the mixer to r-f and I-F terminals is critical, so, in general, the preselector, the mixer and the pre-IF amplifier are best designed together. The optimum impedance transformation between the mixer and the pre-IF amplifier is a compromise between the one giving the mixer the best load impedance and the pre-IF amplifier the optimum source impedance. The matching to the r-f terminal is important. The preselector should see a matched load and all the frequencies generated by the mixer should not be reflected back by the preselector.

5.3.5 Design Considerations

The design of microwave mixers is highly specialized. It is recommended that all mixers above 250 mc be purchased from vendors that are specialists in this field (such as Sage Laboratories, Empire Devices, and others). In order to reduce the number of mixers required for entire receiver frequency coverage, the mixer should be wide-band and yet retain a low noise figure. Octave-wide mixers with a noise figure of less than 7 db (slightly higher above X-band) are presently available. Mixers for frequencies below 250 mc may employ active devices such as transistors. The noise figure of an active mixer is relatively high, about 9 db, but the conversion gain is about 16 db, which overrides the noise due to the I-F amplifier thus maintaining a 9-db overall receiver noise figure.

The I-F preamplifier should be an integral part of the mixer unit since impedance between mixer and I-F preamplifier has a great effect on noise figure. The preamplifier should have a noise figure of less than 2.0 db and a bandwidth of greater than 40 mc. Design of a low noise I-F preamplifier is feasible when using state-of-the-art transistors such as the Philco 2N2364 and Fairchild 2N918. Wide-band feature can be obtained by means of a transmission-line transformer coupling technique discussed in Section 8.

Mixer-preamplifier assemblies are available commercially. LEL and Sage Labs have a working arrangement in this field. Inquiry on their latest development is suggested.

SECTION 6

HARMONIC GENERATORS

6.1 GENERAL

The more important factors which must be considered in designing the local oscillator multiplier chain for use in frequency translation of the original signal frequency to the intermediate frequency (I-F) are listed below:

a. Output power
b. Frequency stability
c. Amplitude stability
d. Low noise operation
e. Good signal-to-noise ratio of the driving oscillator. (Frequency synthesizer output.)

6.1.1. Output Power

The output power requirement is dictated by the particular mixer used. In this receiver, the crystal diode balanced mixer will be used. The r-f power requirement is approximately 1 mw per diode for optimum operation. Because monopulse operation is anticipated, an additional 4 mw is needed. Insertion and mismatch losses must be added to this to bring the total power required to 10-15 mw. A safe power level is 15 mw.

Recent developments indicate that a new form of mixer, the tunnel diode down converter, requires considerably less power - approximately 2-3 microwatts -- for efficient signal conversion. More investigation into this approach is required and this device should be a subject for future study. The results, of course, are directly applicable to this receiver and could do much to reduce the complexity of the r-f generator design.

6.1.2 <u>Frequency Stability</u>

The frequency stability depends upon the user's requirements but, in general, it will be in the magnitude of 1×10^{-8} per day. This figure represents today's optimum stability per investment. Utilization of full receiver capability will involve a stability of 1×10^{-10} per 1-second averaging time. The multiplier should not contribute to frequency instability during these short term averaging time.

6.1.3 <u>Amplitude Stability</u>

Amplitude stability is required to maintain constant power to the mixer section. Also, if modulation is applied to the multiplier, it is desirable to avoid amplitude modulation of the signal due to the bandpass characteristics of the multipliers.

6.1.4 <u>Low Noise and SNR Requirements</u>

The r-f source for the mixer must be low noise sources and free of spurious outputs. The signal-to-noise ratio rapidly deteriorates in multiplication schemes. It is initially desirable to have an extremely high signal-to-noise ratio and to design the multiplier to contribute the smallest amount of noise possible.

6.2 RADIO FREQUENCY CHARACTERISTICS AND DESIGN CRITERIA

Additional requirements placed on the r-f characteristics for this receiver are as follows:

a. The signal should be easily selectable by means of knobs or pushbuttons

b. No returning should be required other than the appropriate frequency selection

c. A power output of 15 mw should be available. (This power would be sufficient to operate three mixers, as may be required in a monopulse type receiver)

d. Spurious outputs should be -60 db from the desired signal

e. Continuous coverage from 100 mc to 10 Gc must be provided

f. The minimum bandwidth coverage for any band selection should not be less than 10 per cent

g. Circuits should be of solid state design

h. Power consumption and size should be a minimum.

Several systems which can achieve the required frequency range are shown in Fig. 6-1.

System 1 of Fig. 6-1 is a varactor multiplier appraoch. The design of these units is well understood at WDL and several multiplier chains have been utilized in various equipment. As a result, the time to achieve a good multiplier design is reduced to a minimum. Although simple in concept, actual design is complex. However, this scheme meets most of the previously listed requirements and will be described in more detail later.

Scheme 2 of Fig. 6-1 can be divided into two parts:

Part one involves a synthesizer which provides outputs to 1 Gc at levels of 15 mw. This signal is applied to a diode waveguide harmonic generator. A TWT is used to amplify the multiplied signal to the appropriate power level.

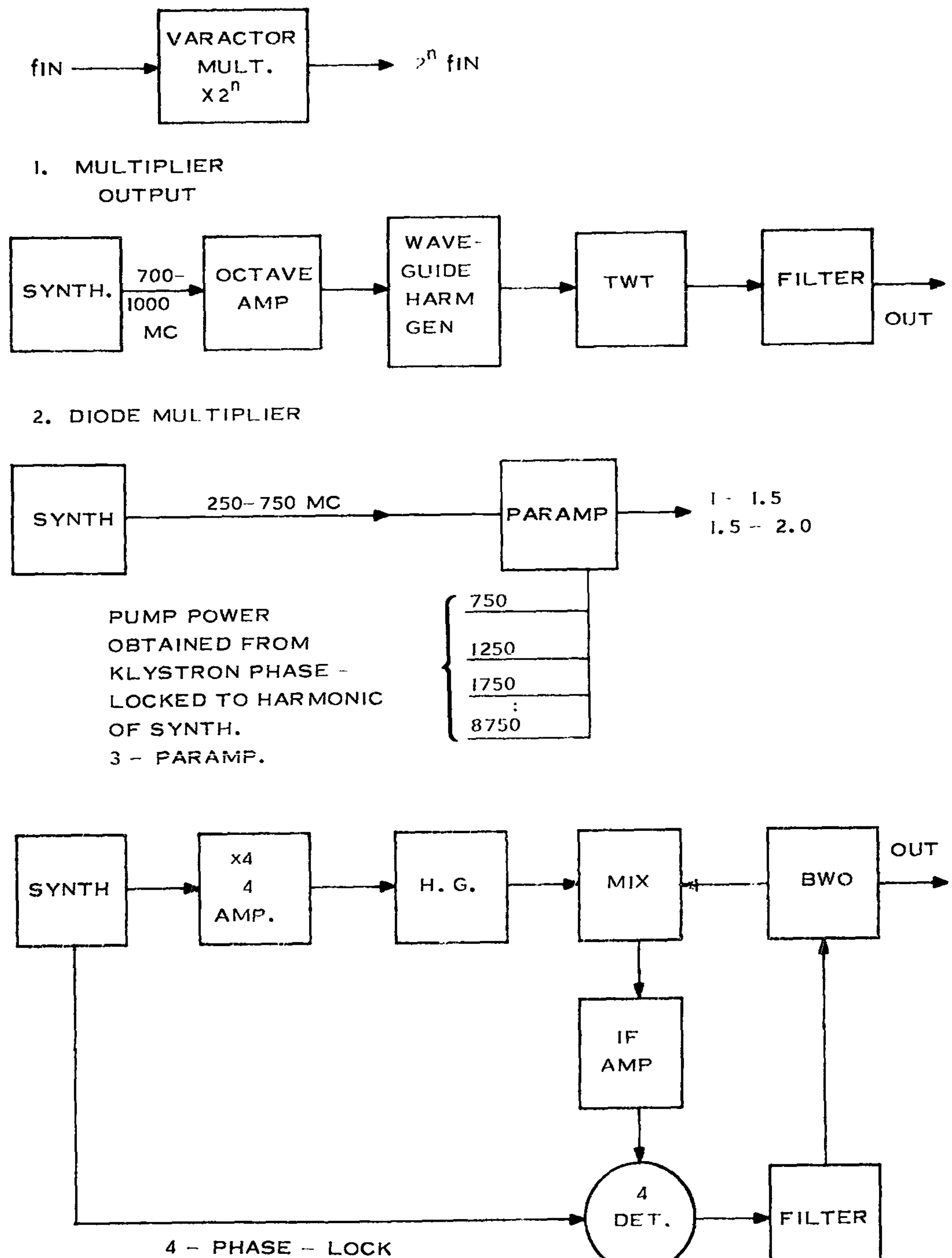


Fig. 6-1 Harmonic Generators

Part 2 consists of using the synthesizer in its normal range up to 66.5 mc, amplifying and multiplying the synthesizer signal to the 500-mc to 1000-mc range. Adequate filters are needed to insure that only the desired frequency is passed. An octave range amplifier will boost the signal power to approximately 15 to 30 mw. The signal is then treated as mentioned in Part one.

A total of 3 TWT's is needed to cover the range of 1 Gc to 8 Gc. The system offers extremely wide-band coverage and is fairly simple. No tuning adjustments are needed -- a situation which makes this system very desirable. However, the system incorporates non-solid state elements, thus reducing the reliability.

System 3 of Fig. 6-1 is simply a parametric up-converter. The synthesizer frequency of 250-750 mc is up-converted to the appropriate bands. The pump frequencies are derived from a synthesizer stage and obtained from one multiplier chain. Since the synthesizer output power is approximately 10 mw, a gain of 1.5 is needed. The disadvantage here is that not much is known of the operation of this type of circuit regarding power level and bandwidth. A further disadvantage is that the pump power must be obtained by phase-locking a klystron to one of the synthesizer standard's outputs or these power levels must be obtained by varactor multipliers. Since only one frequency is needed for each conversion, the varactor multiplier design is pointed toward obtaining effieciency rather than bandwidth. Using the upper side-band, up-converting can yield efficiencies greater than one (desired power-output to signal-power input, disregarding the pump power requirements). The bandwidth is limited only by the components used in the circuity. This is contrasted to the varactor approach in which the efficiency necessarily is impaired to achieve the increased bandwidth.

This method of r-f generation appears quite feasible but the unfamiliarity with the techniques delegates this system to second place. A study contract should be initiated to improve Philco's position in understanding and using these techniques.

System 4 of Fig. 6-1 demonstrates the use of phase-lock in securing "clean" r-f signals. The synthesizer output is miltiplied by a factor of four, amplified and fed to a wave guide harmonic generator. The appropriate harmonic is mixed with the output of a BWO to yield an IF of a convenient value (30 mc). The signal is amplified and phase-locked to the 30 mc synthesized from the IF. The control signal is then passed through a compensation circuit to the BWO to stabilize its frequency. The disadvantage is primarily the need of a search, lock and tracking filter which aids to an already complex system.

6.3 TYPICAL MULTIPLIER STAGE OPERATION

The recommended r-f generator is that of System 1 of Fig. 6-1. The operation of a typical multiplier stage is as follows: The synthesizer output of the first 10 per cent band coverage (31.25 to 34.35) is doubled and amplified to approximately 30 mw. The power is maintained at low level throughout the first I-F bandwidth to avoid the possibility of interference to the received signal. The synthesizer signal is again doubled and now amplified to a maximum level of 5 to 7 watts (this power is required only when X band operation is needed). Fig. 6-2 shows the various power levels and expected circuit efficiencies.

Figure 6-3 indicates that the r-f multiplier consists of many modules. This type of construction yields an extremely flexible system for the user. For example, should operation below 1 Gc be desired, the user may wish to obtain only the necessary components for this range. Should additional frequency coverage be required sometime in the future, the user may obtain the additional components and insert them into the receiver. No redesign or realignment is required.

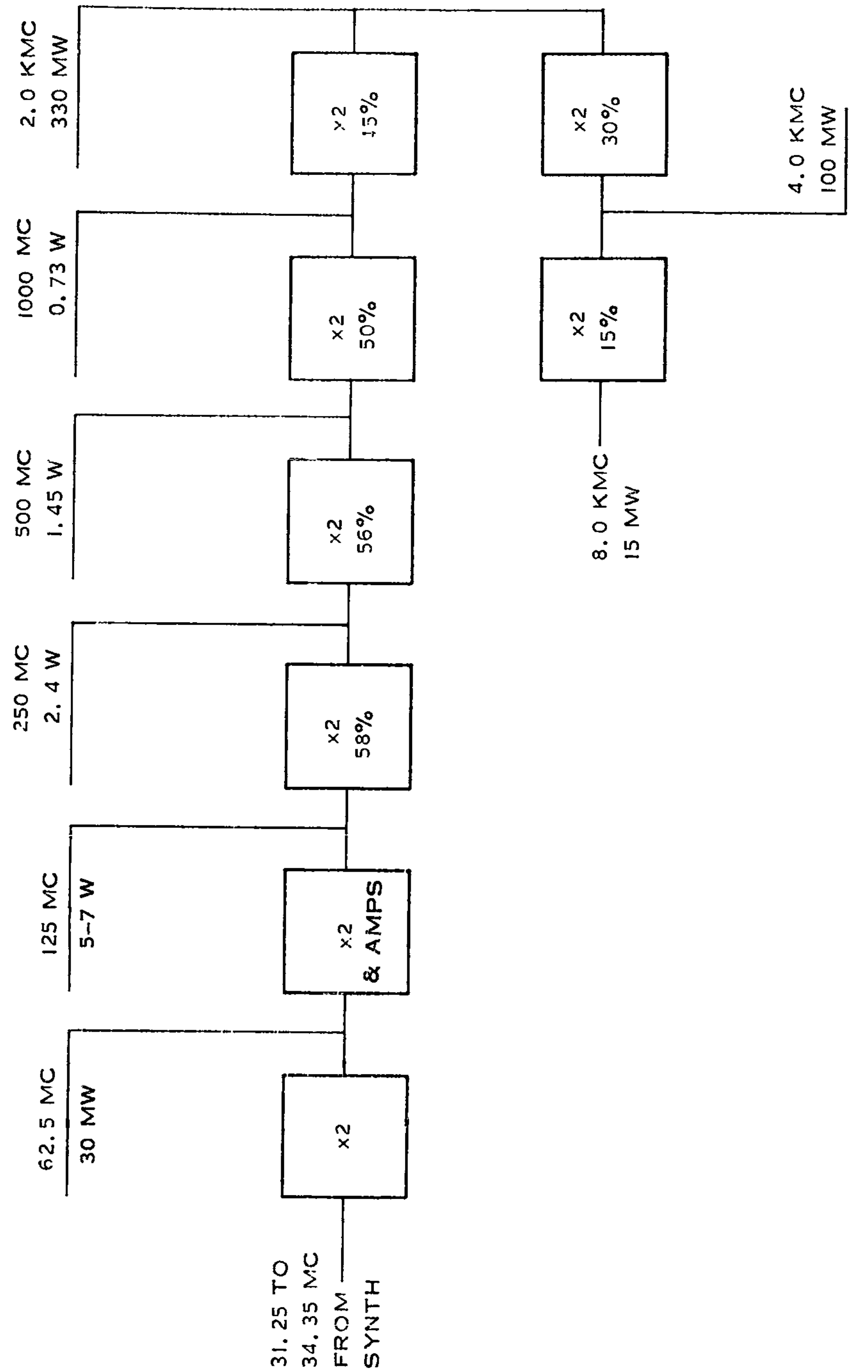


Fig. 6-2 Varactor Multiplier, Chain No. 1.

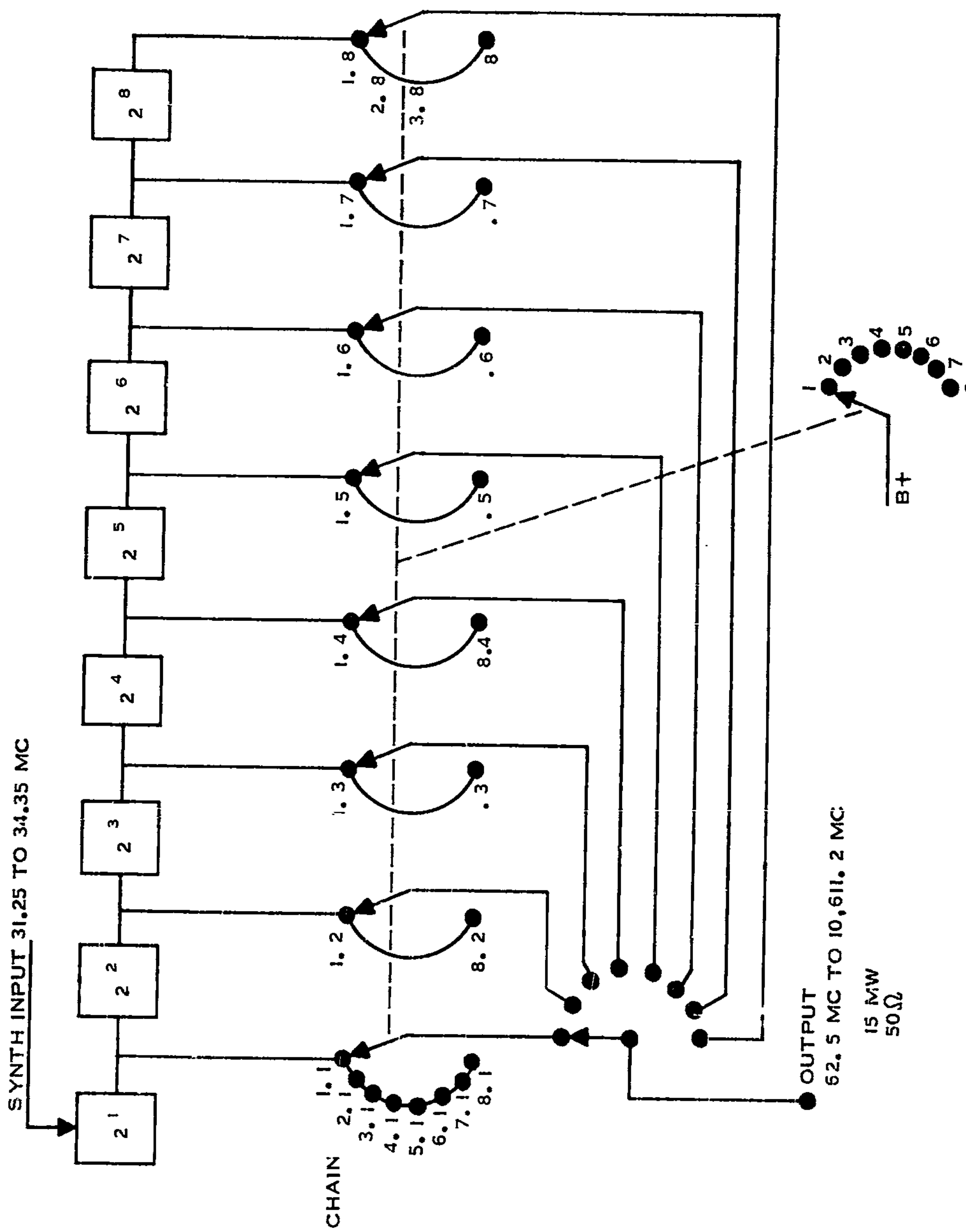


Fig. 6-3 R-F Switching

Is is believed that 10 per cent bandwidth up to 6-cascaded sections is possible. To date, however, much effort has been applied to secure maximum circuit efficiency rather than bandwidth. As a result, little information is available for the determining the exchange of efficiency for bandwidth. An investigation into wide-band varactor multiplier then appears very much needed. The results can be applied directly to this powtion of the receiver.

Finally, remote control operation can be easily achieved. The r-f switches can be electrically operated by solenoid action. Since one-band operation will be required, no special speed requirements are imposed upon the switches.

All outputs of each stage is made available via a filter and at the necessary level of 15 mw. Table 6-1 shows the available frequencies of the multiplier and bands, and Table 6-2 shows the frequency coverage.

In operation, knobs will be used to select the desired frequency output. Only the multiplier chain in use will be activated, a condition which minimizes power consumption and reduces the possibility of r-f interference. The switches can be operated remotely, thereby permitting programmed operation for future use if this type of operation is then desired.

Bandpass filters will be required in the first 3-doubler stages to reduce the sidebands to a value which will not be detected by the I-F amplifiers directly, or will not be mixed with some r-f signal that has not been attenuated sufficiently by the preselector filter.

An all solid-state r-f source, capable of supplying as a minimum power output of 15 mw from 100 mc to 10 Gc can be achieved. No retuning is required. This unit can also be used as a transmitter and be frequency modulated to 10 per cent of the bandwidth. The output power starting at 124 mc is 5 watts decreasing to approximately 0.3 watt at

TABLE 6-1

TUNING RANGE

SIG. FREQ. - MC		BAND	MULTIPLIER	IF
83.9 to	90.1	1	x 2	21 mc
90.1	96.4	2		
96.4	104.3	3		
104.3	112.4	4		
112.4	121.4	5		
121.4	131.4	6		
131.4	142.4	7		
142.4	154.4	8		
146.4	158.4	1	x 4	
158.4	171.4	2		
171.4	187.2	3		
187.2	203.4	4		
203.4	221.4	5		
221.4	241.4	6		
241.4	263.4	7		
263.4	287.4	8		
271.4	296.2	1	x 8	
296.2	323.4	2		
323.4	345.0	3		
345.0	385.4	4		
385.4	421.4	5		
421.4	461.4	6		
461.4	505.4	7		
505.4	553.4	8		
470.0	510.0	6	x 8	69 mc
510.0	574.0	7		
574.0	602.0	8		
569.0	618.6	1	x 16	
618.6	673.0	2		
673.0	732.2	3		
732.2	797.0	4		
797.0	869.0	5		
869.0	949.0	6		
949.0	1037.0	7		
1037.0	1133.0	8		

TABLE 6-1 (continued)

SIG. FREQ. - MC			BAND	MULTIPLIER	IF
1069.0	to	1168.2	1	x 32	
1168.2		1277.0	2		
1277.0		1395.4	3		
1395.4		1525.7	4		
1525.7		1669.0	5		
1669.0		1829.0	6		
1829.0		2005.0	7		
2005.0		2197.0	8		
2069.0		2267.4	1	x 64	
2267.4		2485.0	2		
2485.0		2712.8	3		
2712.8		2921.0	4		
2921.0		3269.0	5		
3269.0		3589.0	6		
3589.0		3941.0	7		
3941.0		4325.0	8		
4069.0		4465.8	1	x 128	
4465.8		4901.0	2		
4901.0		5474.6	3		
5474.6		5893.0	4		
5893.0		6469.0	5		
6469.0		7109.0	6		
7109.0		7813.0	7		
7813.0		8581.0	8		
8069.0		8862.6	1		
8862.6		9733.0	2		
9733.0		10,680.2	3		
965.0		977.4	1	x 4	840 mc
977.4		891.0	2		
881.0		1005.8	3		
1005.8		1022.0	4		
1022.0		1040.0	5		
1040.0		1060.0	6		
1060.0		1082.0	7		
1082.0		1106.0	8		

TABLE 6-1 (continued)

SIG. FREQ. - MC			BAND	MULTIPLIER	IF
1090.0	to	1114.8	1	x 8	840
1114.8		1142.0	2		
1142.0		1163.6	3		
1163.6		1204.0	4		
1204.0		1240.0	5		
1240.0		1280.0	6		
1280.0		1324.0	7		
1324.0		1372.0	8		
1340.0		1429.6	1	x 16	
1429.6		1440.0	2		
1440.0		1503.2	3		
1503.2		1568.0	4		
1568.0		1640.0	5		
1640.0		1720.0	6		
1720.0		1808.0	7		
1808.0		1940.0	8		
1840.0		1939.2	1	x 32	
1939.2		2048.0	2		
2048.0		2166.4	3		
2166.4		2296.0	4		
2296.0		2440.0	5		
2440.0		2600.0	6		
2600.0		2776.0	7		
2776.0		2968.0	8		
2840.0		3038.4	1	x 64	
3038.4		3256.0	2		
3256.0		3492.8	3		
3492.8		3752.0	4		
3752.0		4040.0	5		
4040.0		4360.0	6		
4360.0		4912.0	7		
4912.0		5096.0	8		
4840.0		5236.8	1	x 128	
5236.8		5672.0	2		
5672.0		6145.6	3		
6145.6		6664.0	4		
6664.0		7240.0	5		
7240.0		7880.0	6		
7880.0		8584.0	7		
8584.0		9352.0	8		
8840.0		9633.6	1	x 256	
9633.6		10,504.0	2		

TABLE 6-2

FREQUENCY RANGE OF MULTIPLIER

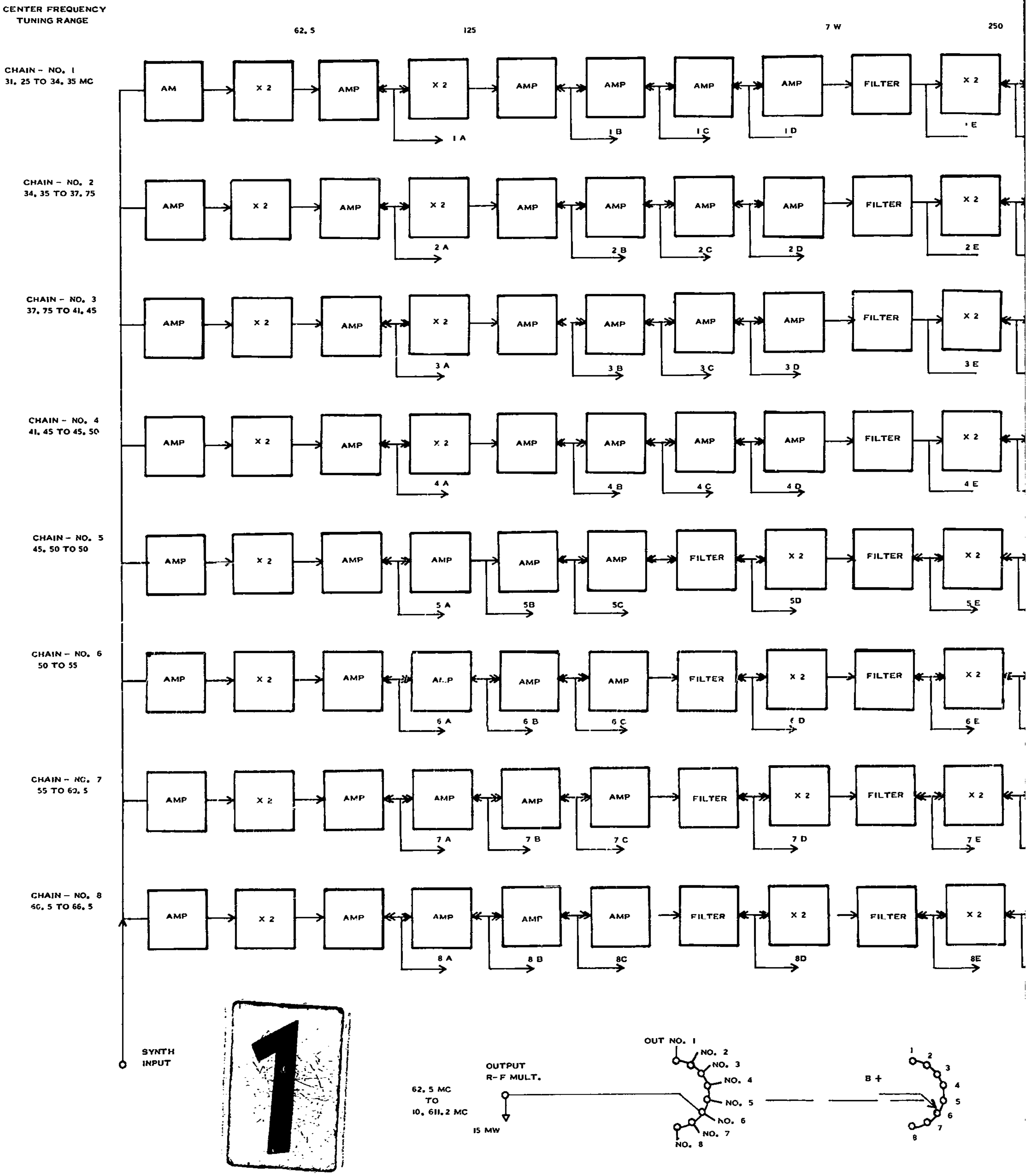
BAND N / 2^n Mult. \ Freq. Mc	1	2	3	4	5	6	7	8
	31.25 34.35	34.35 37.75	37.75 41.45	41.45 45.5	45.5 50	50 55	55 60.5	60.5 66.5
1 X 2	62.5 68.7	68.7 75.5	75.5 82.9	82.9 91.0	91.0 100	100 110	110 121	121 133
2 X 4	125.0 137.4	137.4 151.0	151.0 165.8	165.8 182.0	182.0 200	200 220	220 242	242 266
3 X 8	250.0 274.8	274.8 302.0	302.0 331.6	331.6 364.0	364.0 400	400 440	440 484.0	484.0 532.0
4 X16	500.00 549.60	549.60 604.0	604.0 663.20	663.20 728.0	728.0 800	800 880	880 968	968 1064
5 X32	1000.00 1099.2	1099.2 1208.0	1208 1326.4	1326.4 1456	1456 1600	1600 1760	1760 1936	1936 2128
6 X64	2.000 2198.4	2198.4 2416.0	2416.0 2652.8	2652.8 2912	2912 3200	3200 3520	3520 3872	3872 4256
7 X128	4000 4396.8	4396.8 4832	4832 5824.0	5305.60 6400	5824.0 6400	6400 7040	7040 7744	7744 8512.0
8 X256	8000 8793.6	8793.6 9664	9664 10,661.2					

4 Gc. When used in conjunction with the synthesizer and STALO an r-f signal of extreme frequency accuracy and stability can be obtained. The resolution can be increased to the point where the prime oscillator line width is obtained. This resolution is far greater than can presently being utilized.

Total power consumption has been maintained below 30 watts. Total weight is estimated at 40 pounds.

Although System 1 of Fig. 6-1 requires more hardware, its potential for serving the needs of this receiver is best. As the state-of-the-art improves, the system improves. Although the same philosophy can be applied to system 3, at present more appears to be know about varactor multipliers. Accordingly, more attention will be placed on this first system.

A more detailed description of this system is shown in Table 6-1. A synthesized output of 31.5 mc to 66.5 mc is needed. The total number of doublers needed per chain is 7 with the exception of the first 3, which require 8 doublers. Of course, the chains would be very similar, a situation which would aid the design time considerably. (See Fig. 6-4.)



CENTER FREQUENCY
TUNING RANGE
62.5
125
7 W
250
CHAIN - NO. 1
31.25 TO 34.35 MC
CHAIN - NO. 2
34.35 TO 37.75
CHAIN - NO. 3
37.75 TO 41.45
CHAIN - NO. 4
41.45 TO 45.50
CHAIN - NO. 5
45.50 TO 50
CHAIN - NO. 6
50 TO 55
CHAIN - NO. 7
55 TO 60.5
CHAIN - NO. 8
60.5 TO 66.5
AMP
X 2
FILTER
1 A
1 B
1 C
1 D
2 A
2 B
2 C
2 D
2 E
3 A
3 B
3 C
3 D
3 E
4 A
4 B
4 C
4 D
4 E
5 A
5B
5C
5D
5E
6 A
6 B
6 C
6 E
7 A
7 B
7 C
7 D
7 E
8 A
8 B
8C
8D
8E
SYNTH
INPUT
1
OUTPUT
R-F MULT.
62.5 MC
TO
10,611.2 MC
15 MW
OUT NO. 1
NO. 2
NO. 3
NO. 4
NO. 5
NO. 6
NO. 7
NO. 8
B +
1
2
3
4
5
6
7
8

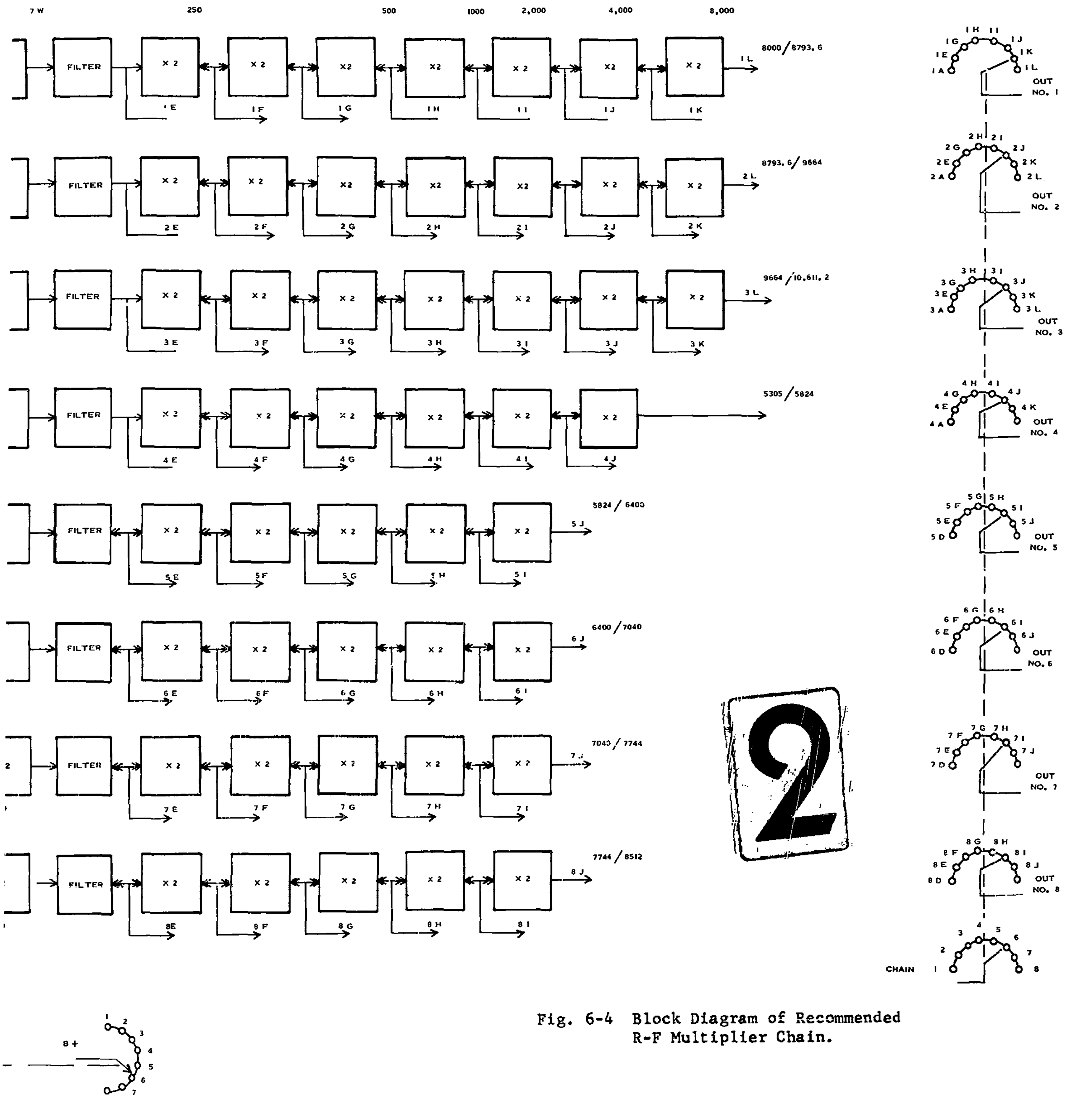


Fig. 6-4 Block Diagram of Recommended R-F Multiplier Chain.

SECTION 7
FREQUENCY SYNTHESIZER AND LOCAL OSCILLATOR

7.1 FREQUENCY SYNTHESIZER

As more satellites and spacecraft appear on the scene, the need for coverage of greater r-f spectrum becomes greater. Most receivers are now being designed for one frequency or, at most, a band of frequencies. Changing frequency coverage is usually a major redesign because a new r-f range must be considered. This problem can be alleviated immensely by the use of a frequency synthesizer which can generate any one frequency from a great number by simply turning knobs. With the use of a synthesizer of this sort, the problem of extending the usefulness of the receiver is mostly solved. Indeed, with this scheme, the problem of the receiver, as far as frequency coverage with high stability is concerned, has been greatly simplified. This device and the r-f multiplier chain constitute a stable local oscillator for frequency conversion.

The synthesizer, then, is the basic element for obtaining stable wide frequency coverage. In general, a synthesizer is a unit which, as a result of combining a few internal frequencies, can yield selectively one of a great number of frequencies. More specifically, for this program a more rigorous definition of a synthesizer is as follows. A synthesizer is a unit which provides any one of may frequencies which have been derived from one frequency source called the referenced standard frequency. The reason for placing the restriction of deriving all frequencies from one reference will be discussed in more detail later in this section.

At this point, consideration must be given for the desired synthesizer characteristics. Accordingly, the following specifications would be desirable:

1. The synthesizer shall generate the desired frequency by simple manipulation of switches or push buttons. No re-tuning and adjustment should be allowed or necessary. The output frequency

should require no calibration or any additional equipment to verify its frequency. The frequency selected should be directly readable on the indicating knobs or push buttons.

2. The output frequency must be free of spurious components. A tentative specification shall be that all spurious components be 60-db down from the desired signal.

3. The output signal characteristics shall be equal to the reference driving signal as far as drift and stability (short term and long term) are concerned.

4. The range of frequency synthesis shall be as large as possible. A minimum for this program should be 100 cycles to 30 mc in 100 cycle steps.

5. The stages shall be as similar as possible in order to minimize design time, stocking parts, etc.

6. The nearest sideband shall be no closer than 100 kc from the desired frequency.

7. High reliability and low cost shall be a design criterion.

8. A simple attachment to compute the frequency to which the receiver is tuned by the synthesizer shall be made available. This computer would solve the equation:

   $F_{\text{signal input}} = F_{if} + (N)\ F\ \text{synthesizer} + F\ \text{translation}$:

   where F_{if} = frequency, intermediate

   N = multiplication factor (2 to 256)

   F synthesizer = synthesizer frequency

   F translation = the frequency which is mixed or combined with the synthesizer output to achieve the desired frequency translation.

9. The receiver shall be adaptable to operation by a computer.

10. The ratio of any two signals which are mixed should not exceed 10:

    i.e. $\frac{f_2}{f_i} \leq 10$

The initial restriction which requires that the synthesizer output be a function of any one input results from normal use of the receiver during narrow-band operation. Phase or frequency stability is most critical at these times. Although by careful design the necessary stability can be achieved, the price paid for choosing multiple sources synthesizer is design time and component cost. Far more preferable would be that type of synthesizer which reduces both design time and cost and permits the output frequency to have the same stability characteristics as the input frequency. The customer would then have greater freedom in selecting the stability requirements for his need. However, only one synthesizer has been designed to satisfy all possible needs.

In this section, only a brief discussion can be made of various types of synthesizers. Synthesis through combination of more than one driving source has been excluded; however, for the sake of completeness, mention should be made of several types that are in existence. The following list includes only a few of the synthesizers of this type.

- Bendix frequency synthesizer
- Bendix system for Radio Set AN/ARC-33
- Collins system for Radio Receiver R-278-GR
- Collins system for Radio Set AN/ARC-27

7.2 RECOMMENDED SYNTHESIZER

The following synthesizers function according to the first restriction (one driving source only), and will be examined:

- The Plessey
- Shomandl
- Manson
- Rhode-Schwarz
- AN/URT-2

- General Radio Company
- I.T.T. Controlled Oscillator
- Binary
- National Co. Synthesizer

The National Synthesizer, possesses the ten characteristics outlined in paragraph 7.1 and accordingly will be examined first. The block diagram is shown in Fig. 7-1. A more detailed explanation for this synthesizer will be given since it appears most promising for this program. The basic principle involved is as follows: The first digit of a number to be synthesized is selected and then divided by 10; the next digit is mixed with this result and the sum or is again divided by 10. The procedure is repeated until the desired number is generated. Because it is desirable to handle only a 10 per cent variation in bandwidth, a carrier is added to accomplish this purpose.. The block diagram of Fig. 7-1 is useful in understanding the operation.

Utilizing the carrier, the synthesizer operation can be expressed as:

$$f_2 = \frac{f_i + f_{xi}}{n} \qquad (7\text{-}1)$$

$$f_3 = \frac{f_2 + f_{xi}}{n} \qquad (7\text{-}2)$$

$$f_4 = \frac{f_3 + f_{xi}}{n} \qquad (7\text{-}3)$$

$$f_4 = \frac{\frac{f_2 + f_{xi}}{n} + f_{xi}}{n} \qquad (7\text{-}4)$$

$$f_4 = \frac{\frac{\frac{f_i + f_{xi}}{n} + f_{xi}}{n} + f_{xi}}{n} \qquad (7\text{-}5)$$

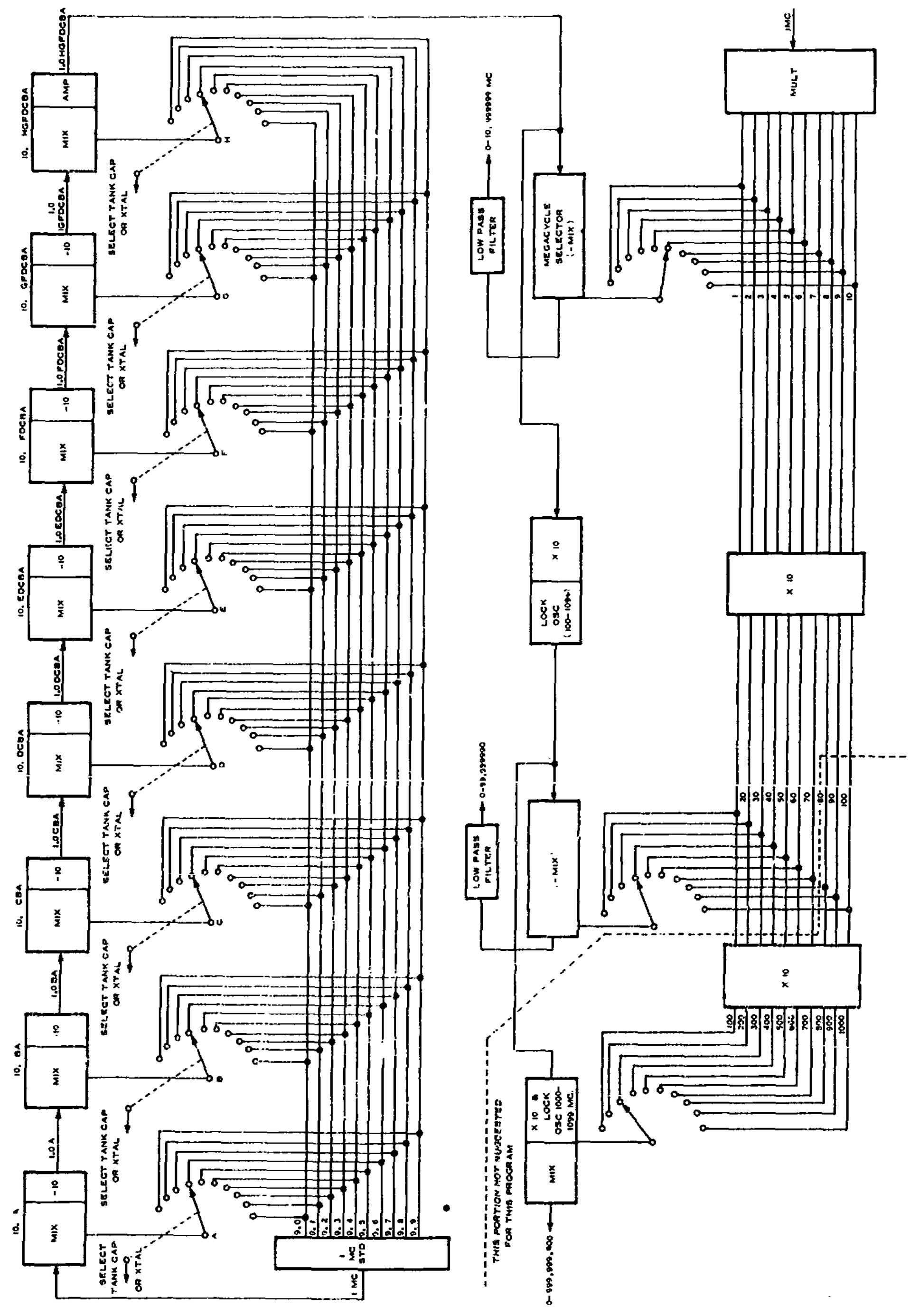


Fig. 7-1 National Company Synthesizer

or as the fraction

$$f_n = \cfrac{\cfrac{\cfrac{\cfrac{\cfrac{f_1 + f_{xi}}{n} + f_{x2}}{n} + f_{x3}}{n} + f_{x4}}{n}\ \vdots\ + f_{xx}}{} \qquad (7\text{-}6$$

In this expression, n represents the radix of the system used and $f_1 = 1 < f_{.} < 1.1$ and $f_{xi} \; . \; . \; . \; f_{xx}$ is a number = radix system - 1.

<u>For example</u> if the radix = 6 then f_{xi} . . . is 5.0, 5.1, 5.2, 5.3, 5.4, and 5.5.

To obtain the number 1.231_6 the following operations are performed (the sub-six indicate base 6)

$$f_1 = \frac{1 + 5.1}{6} = 1.01_6 \qquad (7\text{-}7)$$

$$f_2 = \frac{1.01 + 5.3}{6} = 1.031_6 \qquad (7\text{-}8)$$

$$f_3 = \frac{1.031 + 5.2}{6} = 1.0231_6 \qquad (7\text{-}9)$$

Now multiply by 6 and subtract 5

$$10.231_6 - 5 = 1.231_6 \qquad (7\text{-}10)$$

$$1.231_6 = 1.4213_{10} \qquad (7\text{-}11)$$

This synthesizer based on radix 10 will be used for this receiver. The base of 10 is chosen to simplify calculating for the operator's convenience. The synthesizer then operates as follows. Assume it is desired to obtain 1.728 the f_{xi} = 9.0, 9.1, 9.2, 9.3, ... 9.9.

The operations are as follows:

$$\frac{1 = 9.8}{10} = 1.08 \tag{7-12}$$

$$\frac{1.08 + 9.2}{10} = 1.028 \tag{7-13}$$

$$\frac{1.028 + 9.7}{10} = 1.0728 \tag{7-14}$$

Now, multiply by 10 and subtract 9, to give 1.728. In this synthesizer the last division by ten is omitted because of the following frequency translation which is needed.

The degree of resolution can be increased easily as can be seen by equation 7-6. The degree of resolution is governed by the range of the receiver VCO. The VCO should operate about its normal center for optimum performance: the resolution of the synthesizer has been determined to maintain the VCO to within 7 per cent of its normal center frequency. The synthesizer is designed for a resolution of 1×10^{-6} which is required for operation in the X-band, however, the resolution can be increased or decreased by simply adding or removing divider circuitry which are of the plug-in-type.

As mentioned previously, an up-frequency translation is required. The synthesizer must supply frequencies in the range from 31.4 mc to 66.5 mc. To accomplish this range the synthesized output which appears as 10. n . . . . CBA is multiplied by 10. Again the variable part which is .n . . . . CBA are single-tuned circuits. After multiplication, the signal 10 n. . . .CBA, lies between 100 mc and 109.$^+$ mc. To obtain the range of 30 to 39. $^+$, the 70 mc mixer signed is subtracted from the 100-109 mc. The 60 to 40 are used respectively to obtain synthesizer outputs from 40 to 69.9 mc. In this manner the synthesizer outputs are obtained. It is to be noted that no "tricky" switching is needed to increase the resolution. The circuitry is all quite straight forward without the necessity of special balanced modulators or filters. Side-bands have been reduced and the operation has been reduced to an extremely simple procedure of setting knobs.

The operation of the synthesizers first of all requires a bank of signals 9.0 to 9.9. It is these digits which are used to synthesize the required number. Initially, the 1 mc from the standard is mixed with the last digit of the synthesized number. Using the example of 36,728, the number 9.$\underline{8}$ is selected from the bank of signals. The sum 10.8 is divided by ten to shift the decimal place one unit to the left. The resultant 1.08 is again mixed with 9.$\underline{2}$ to obtain the next digit of the number. The sum 10.28 is again divided to shift the decimal one place to the left. The 9.7 mc is mixed with 1.028 divided by ten to yield 1.0728. The 9.$\underline{6}$ is mixed with 1.0728 to obtain 10.6728. Normally this number would be divided by ten. However, this step is omitted at this stage to translate the frequency to the 30-mc region. The 10.6728 is multiplied by 10 to 106.728 mc and finally the mixer signal of 70 mc is subtracted from the result to obtain the 36.278 mc.

After a little study, it becomes apparent that this synthesizer has met the ten requirements of paragraph 7.1. The unit resolution can be improved by cascading as many divide by 10 and mixing operations as resolution may require. Each operates over the same range, and the nearest side-band in this case is 1-mc from the desired signal. The range of synthesis can be made from 0 to 999.9999 mc as shown in Fig. 7-1, but for this program, it will be limited to 30-69.9$^+$ mc as shown in Fig. 7-2. The stability is equal to the driving frequency's stability. Spurious output is less than -60 db because of the phase lock operation. The diagram Fig. 7-3 shows a tentative divide by 10 circuit. The oscillator operating at 1/10 of the input frequency is phase locked with the incoming signal. However, many other schemes are available to achieve the same purpose. A regenerative divider by 10 is possible although the reliability of these types of circuits is somewhat questionable. Other schemes, divide by 2 or passive divide by 2 with a regenerative divide by 5, are also possible.

The range of operation, the ease of obtaining additional resolution and the freedom from sidebands makes this synthesizer a truly ideal unit. The design is minimal since the divide by 10 stages are identical in all units.

The adaptability of this unit to remote control further enhances its utility. The switch can be replaced by an equivalent binary decoder. In this method, the synthesizer can be programmed from a computer.

It is this synthesizer approach, the National Company synthesizer type, that is recommended for further investigation for use in this receiver. At present, this was an early concept developed at the National Company and there should be no reason why the hardware could not be developed at the Philco Corporation.

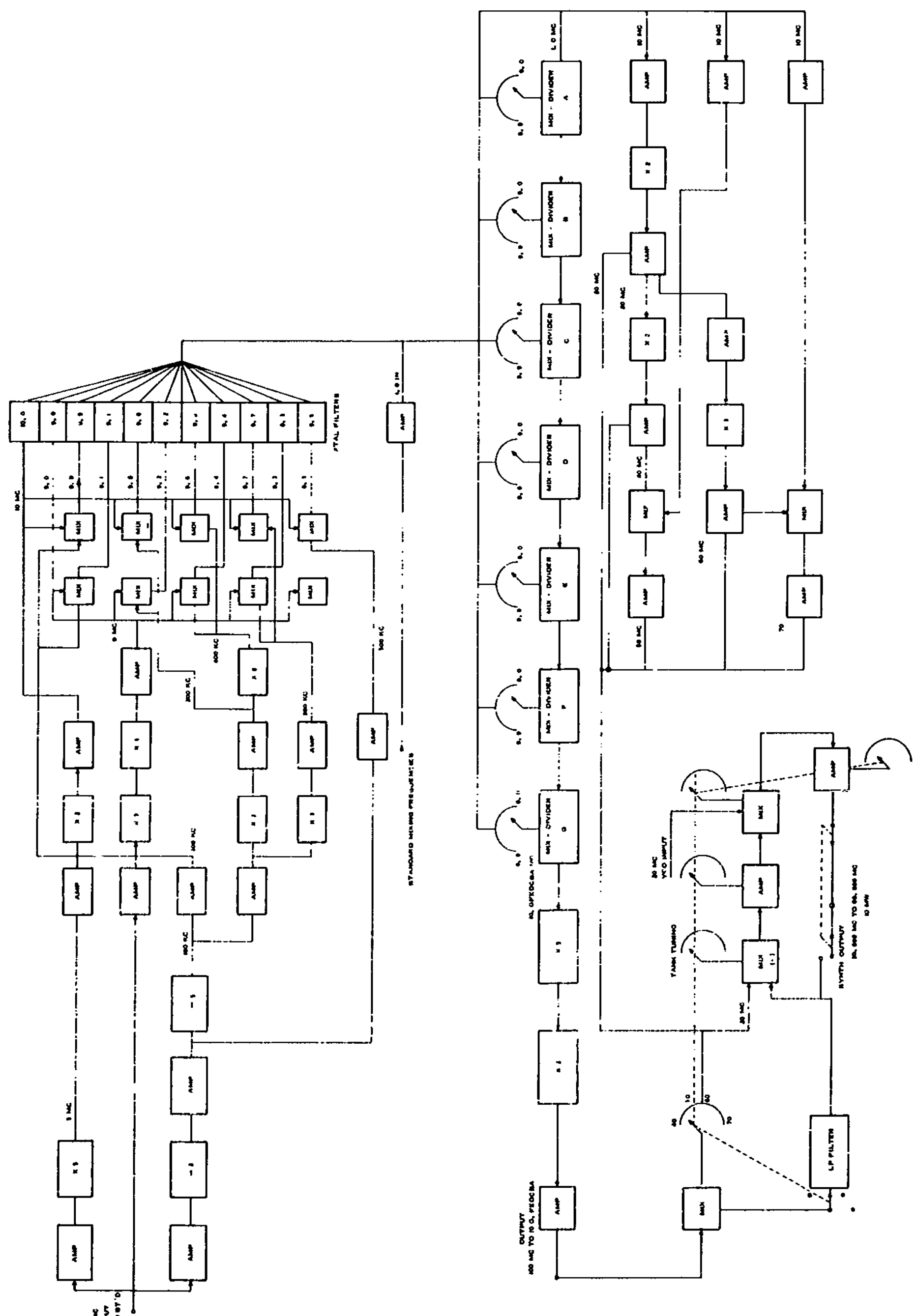


Fig. 7-2 Recommended Frequency Synthesizer

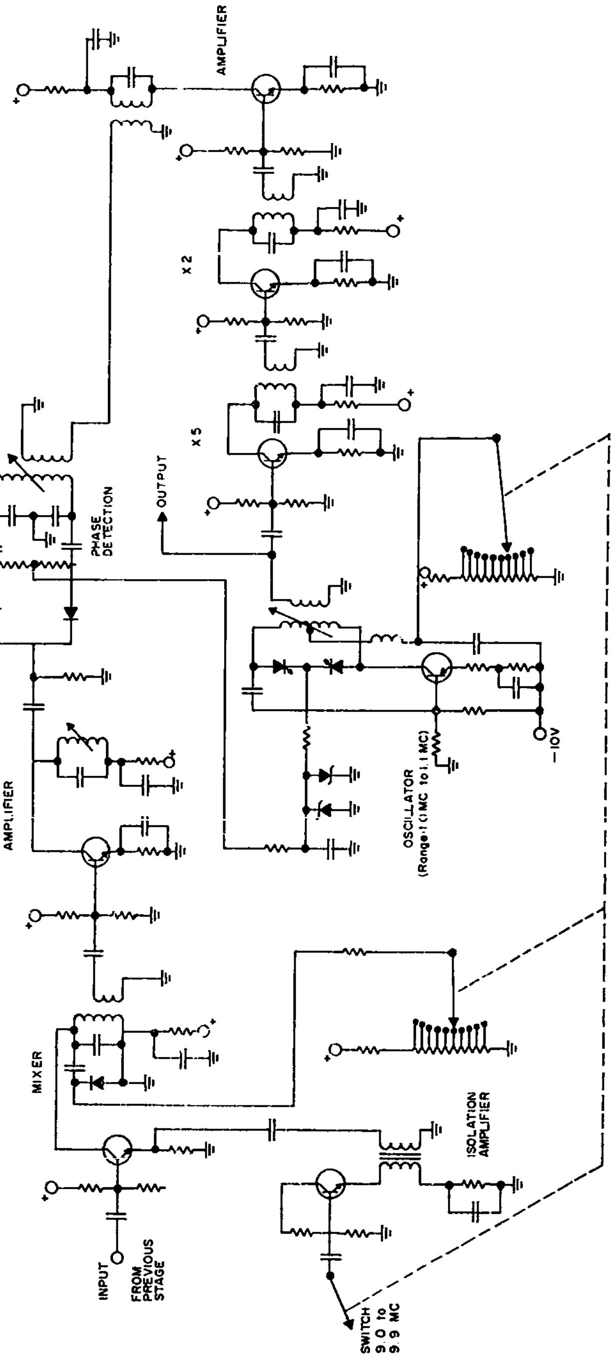


Fig. 7-3 Mixer and Divide by 10

The synthesizer has provision for mixing with the VCO output. This type of operation is needed when first mixer-phase or frequency lock is used. When this situation prevails, the VCO is mixed with the output of the synthesizer which has been reduced by a fixed 20 mc. The resultant output signals cover the same frequency range but now has the advantage that it can be modulated by the VCO. This output can now be varied as much as 10 per cent.

The block diagram in Fig. 7-4 shows how this operation is accomplished. The synthesizer output is mixed with 20 mc, which is generated by the synthesizer and the resultant signal at 11 to 46 mc is amplified and mixed with the VCO output. The final signal is applied to the r-f multiplier chain.

Voltage controlled variable bandwidth filters will be necessary at the output of each mixer to filter unwanted mixer products and signals.

7.2.1 STALO (Reference Oscillator)

The input reference signal specifications are contingent upon the signal to be received. In order to utilize the receiver to full capability the reference oscillator should be of high stability (both long and short term) reference standard. For deep space tracking, an atomic standard such as the National Company NC-2001 or NC-1501 should be used. For normal satellite work, an improved Hewlett-Packard HP-104 is sufficient.

7.2.2 Operator Use

The frequency synthesizer will need to have a display reading in decimal digits for the received frequency. The controls of the synthesizer must be easy for the operator to use without the need of complicated reference charts. A small mechanical digital computer may be necessary to accomplish this result in a convenient manner.

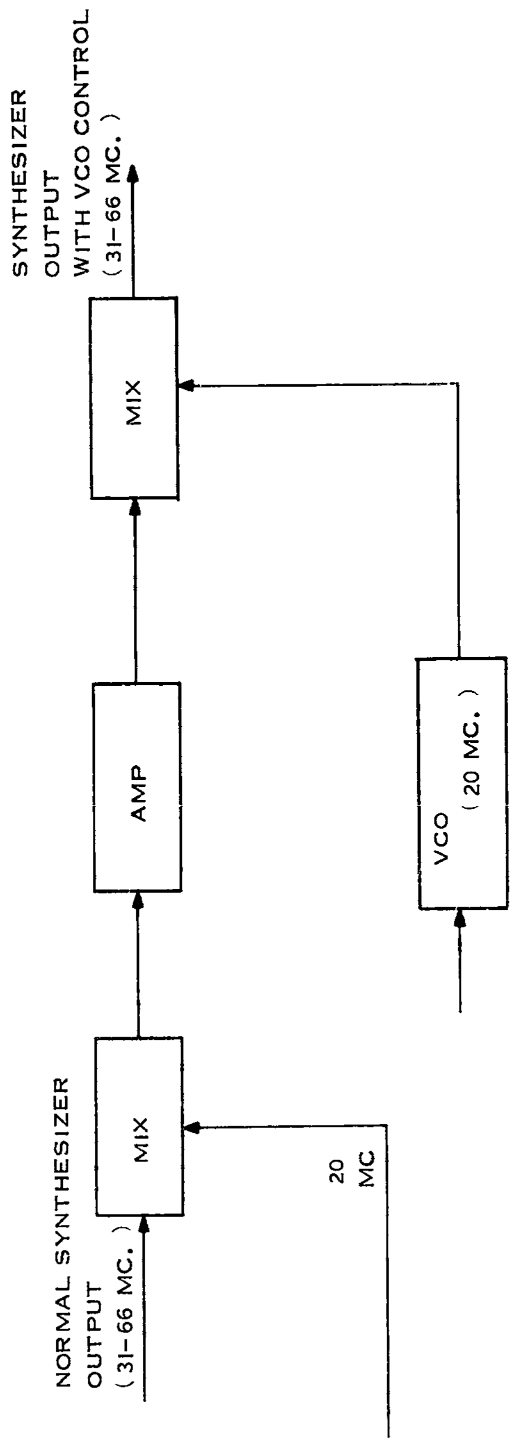


Fig. 7-4 Synthesizer Adaptation Using VCO

7.2.3 Automatic Read-Out of Incoming Signal Frequency

Automatic read-out of the frequency of the incoming signal can be provided in the multipurpose receiver by using either of two devices:

1. Mechanical calculator
2. Digital computer.

Option 2 is included for sites where a computer has extra capability and can solve the equation:

$$f \text{ signal} = (f \text{ synthesizer})\ (f \text{ band}) + f_{IF} \qquad (7\text{-}15)$$

Option 1 uses a Victor "digitmatic" calculator with electronic read-in and read-out and associated logic to solve equation (7-15). Table 7-1 lists the steps in solving the equation. The correct keys in the calculator are depressed by the logic unit energizing the correct solenoid.

A mechanical calculator is used because:

a. Its cost is much less than an equivalent digital computer.

b. It is reliable (over 16,000,000 cycles without failure is typical).

c. It provides a printed record of incoming signal frequencies which may include a GMT time print-out after each frequency print-out and additional numbers or characters for record.

The logic circuits are arranged so that whenever the synthesizer is reset to a new frequency the calculator automatically solves equation 7.15 by scanning the synthesizer switch settings into the calculator and by reading the position of the "IF FREQUENCY SELECT" switch. The accumulated sum in the calculator (incoming signal frequency) is used by the logic unit to drive the display lights at the receiver and at one or more remote locations. The printer also prints out on paper type the incoming frequency.

The "READ SIGNAL FREQUENCY" cycle is initiated by depression of the "SET FREQUENCY SYNTHESIZER" button. A counter interlocked with the calculator, steps through the program listed in Table 7-1.

7.2.4 Tuning Procedure

To tune the receiver to the desired input frequency, the operator must have a prior knowledge of the approximate frequency of the incoming signal. The band is selected by varying the "Tuning Range" and "Band Selection" knobs. A display shows the band coverage permitted by the knob setting. When the desired band is obtained, the operator sets the knobs of the synthesizer panel for the particular range. The mechanical computer performs the required operations as stated previously. The synthesizer frequency is varied until the incoming signal is positioned in the center of the receiver passband.

7.3 PLESSEY AND SCHOMANDL SYNTHESIZER

The Plessey synthesizer appears to have been the first type in commercial usage. Accordingly, a detailed explanation will be given for this type which will also suffice for the similar one, the Schomandl.

The circuit system by which the Plessey synthesizer produces thousands of frequencies, all controlled by a single 1000-kc crystal standard, is illustrated in Fig. 7-5. The block diagram shown is that of the original, single-cabinet model that permit the operator a choice of any one of the first 10,000 harmonics of 1 kc. It can be seem that there are three successive stages in which the input frequency is divided by 10, so that the last divider represents an over-all division of the original standard (1000 kc) by 1000. The dividers and the 1000-kc harmonic generator are of the synchronized, free-running multivibrator type whose outputs are rich in harmonics. Each of these multivibrator circuits forms the first stage of a sequence which can be tuned to pass any one of the first 10 harmonics of its respective multivibrator fundamental. These sequences are labeled A, B. C. and D in Fig. 7-5.

TABLE 7-1

Control of Victor Digimatic Calculator

1.	Cycle starts with depression "SET SYNTHESIZER" button	
2.	Constant lever to "NO CONSTANT" position	Clear
3.	Total button to "TOTAL"	Clear
4.	Motor bar depressed	Clear
5.	Constant lever to constant position	f band
6.	Master control lever to "MULTIPLY"	f band
7.	Enter band number via keyboard	f band
8.	Depress motor bar	f band
		(x)
9.	Enter synthesizer setting via keyboard	f synthesizer
10.	Total button to SUBTOTAL"	f synthesizer
11.	Depress motor bar	f synthesizer
12.	Constant lever to "NO CONSTANT" position	f synthesizer
		(+)
13.	Set master control lever to "PLUS"	f_{IF}
14.	Enter i-f frequency via keyboard	f_{IF}
		(=)
15.	Total button to "TOTAL"	f signal
16.	Depress "PLUS" bar	f signal

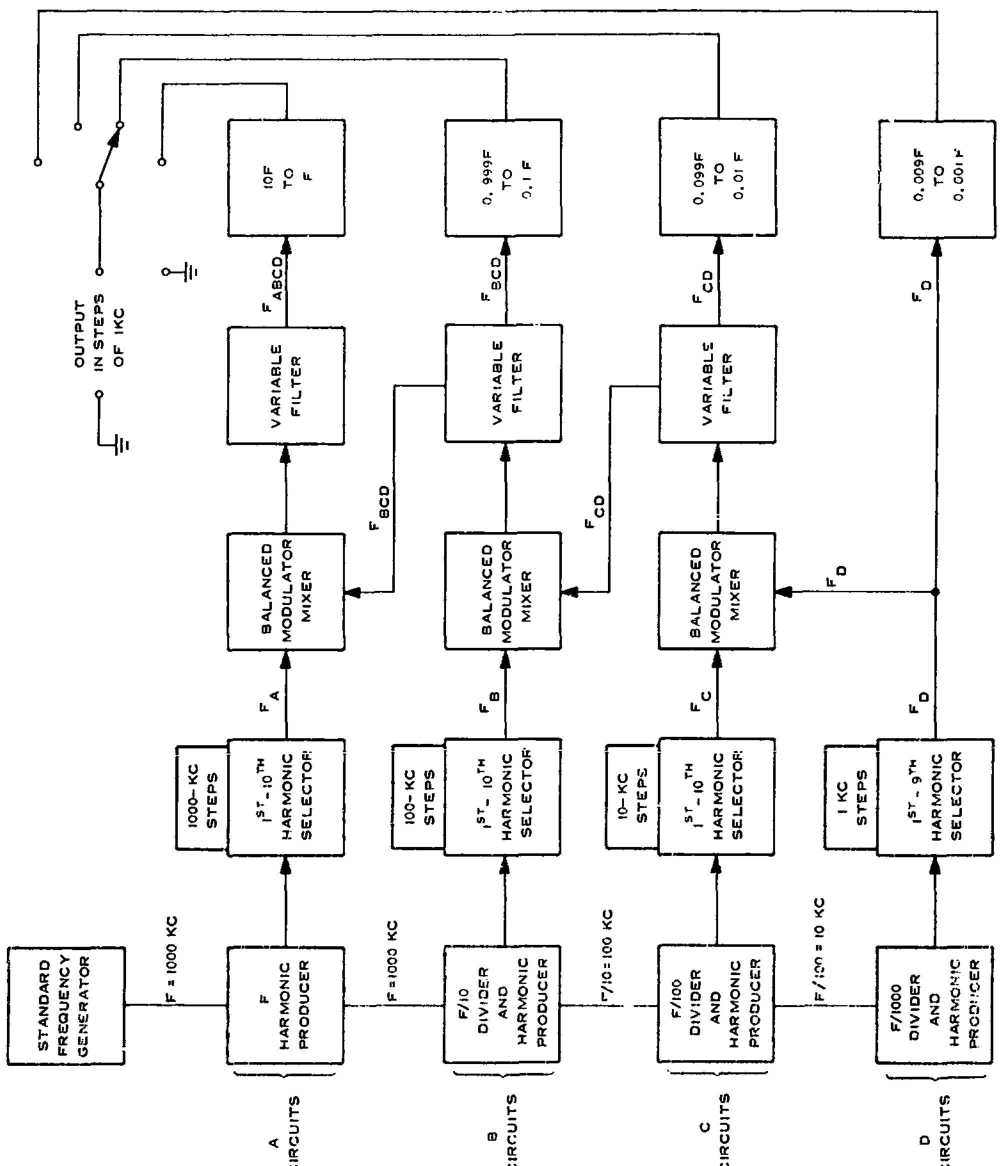


Fig. 7-5 Plessey Synthesizer

In the synthesis of a frequency, we can say generally that sequence A supplies that part of the final frequency which is a multiple of 1000 kc; B that part which is a multiple of 100 kc; C that part which is a multiple of 10 kc; and D that part which is a multiple of 1 kc.

For example, assume that an output frequency of 7698 kc is desired. The A, B, C, and D harmonic selectors, respectively, will be decade-set to pass the 7th, 6th, 9th, and 8th harmonics of their respective input singals from the preceding multivibrator stages. In balanced modulator C, the output of selector D, 8 kc, is mixed with the 90-kc output of selector C. (The signals are heterodyned in a balanced modulator circuit rather than in a more efficient type of mixer in order to eliminate the low input frequencies from the modulator output. In this manner, the sum and difference products become the dominant frequencies in the modulator output.) Filter C is dial-set to pass the desired frequency product (98 kc) which it feeds to balanced modulator B. In modulator B, the 98-kc signal is heterodyned with the 600-kc output of the decade-set harmonic selector B. Filter B is dial-set to pass the sum product (698 kc) from the B modulator output to the A modulator input, where it is mixed with the 7000-kc output of harmonic selector A. Filter A is dial-set to pass the sum product (7698 kc) of the mixed signals, which product is then amplified and fed through a phase inverter to the synthesizer output jack.

The foregoing example of the operation of the Plessey synthesizer suggests that the sum rather than the difference products of the mixed signals are always selected. In practice this is not the case, even though the decade dialing system is so designed that the operator is always provided a direct reading of the output frequency as if he were only adding the decade units together. In order to filter out the unwanted product sufficiently, it is important that the signals to be mixed be selected to provide at least a 10 per cent difference in frequency between the sum and difference products. Since the filters

must be capable of suppressing all adjacent harmonics of the mixed signals, it can be assumed that they are also capable of suppressing the unwanted heterodyne product if it differs from the desired product by as much as the fundamental harmonic of the modulator input from the haromonic selector. For example, in modulator C, the space between the sum $(f_c + f_d)$ and the difference $(f_c - f_d)$ should not be less than 10 kc, the fundamental of the harmonic from selector C. Since,

$$(f_c + f_d) - (f_c - f_d) = 2f_d \qquad (7\text{-}15)$$

which is 10 kc, then f_d must never be less than 5 kc if it is t be mixed with f_c. Similarly, f_{cd} must not be less than 50 kc if it is to be mixed with f_B; and f_{bcd}, must not be less that 500 kc if it is to be mixed with f_a.

To illustrate, let us suppose that a frequency of 91 kc is desired. It would not do for f_c and f_d to be 90 kc and 1 kc respectively, for then the sum product, 91 kc, would be separated from the difference product, 89 kc, by only 2 kc. Rather, 100 kc should be selected as f_c and 9 kc as f_d. The variable filter C would be set to pass the difference product, 91 kc; which product differs from the sum product, 109 kc, by 18 kc, well beyond the minimum permissible limit of 10 kc.

As a more involved example the heterodyne frequencies that would be used in the synthesis of an 8136 kc output will now be determined. For a mental calculation of the correct frequency combinations the easiest method is to start with the output frequency, f_{abcd}, and from this determine f_a, f_{bcd}, f_b, f_{cd}, f_c, and f_d in that order, working from the larger units to the smaller. Each of the above six frequencies is determined by remembering that none of the input frequencies to the A, B, and C modulators can be less that 500, 50 and 5 kc, respectively. Thus, we see at once that 8135 kc is not to be the sum product of 8000 kc and 136 kc in the A modulators, since 136 kc is less than 500 kc. So f_a must be 9000 kc and f_{bcd} must be 1000 minus 136 kc, that is, 864 kc,

which means that filter A will be adjusted to pass the difference product (9000 kc minus 864 kc). Since 64 kc is greater than 50 kc, the required 864 kc output of modulator B can be obtained as the sum product of 800 kc and 64 kc, f_b and f_{cd}, respectively. Since 4 kc is less than 5 kc, the required 64 kc output of modulator C must be obtained as the difference product of 70 kc and 6 kc, f_c and f_d, respectively. We see that in order to select an output of 8136 kc, the decade dials of the A, B, C, and D harmonic selectors must be set to pass, respectively, the 9th 8th, and 7th and 6th harmonics. In other words, the output frequency would be a synthetic product of the four frequencies, 9000 kc, 800 kc, 70 kc, and 6 kc. Also, it would be an output frequency of 9876 kc. Since the decade dials that control the harmonic selectors may be set at the same positions for two or more frequencies, some arrangement must be made so that the decase reading presented to the operator identifies correctly the particular frequency being synthesized. This convenience is accomplished in the Plessey synthesizer by manually operated range adjustments that alter the correspondence of the dial readings with the dial positions. Thus, in the example above, with the proper range settings, Decade Dial A in Position 9 would give a reading of 8, Decade Dial B in Position 8 would give a reading of 1, Decade Dial C in Position 7 would give a reading of 3, and Decade Dial D in Position 6 would give a reading of 6. The mechanics of exactly how this feature is incorporated in the Plessey synthesizer, although relatively simple in principle, is somewhat beyond the subject matter of this report.

The block diagrams of the Manson, Fig. 7-6, and Schomandl, Fig. 7-7, have been included to demonstrate practical applications of the synthesizer scheme.

7.3.1 Disadvantages

Although extension of this system to improve resolution is possible, the problem becomes more difficult. For example, if 100 cycle resolution is desired at S-band, the synthesizer must be capable of generating signals to the "units" place. Tuned circuits become awkward and the design more difficult. The elimination of sidebands is severe.

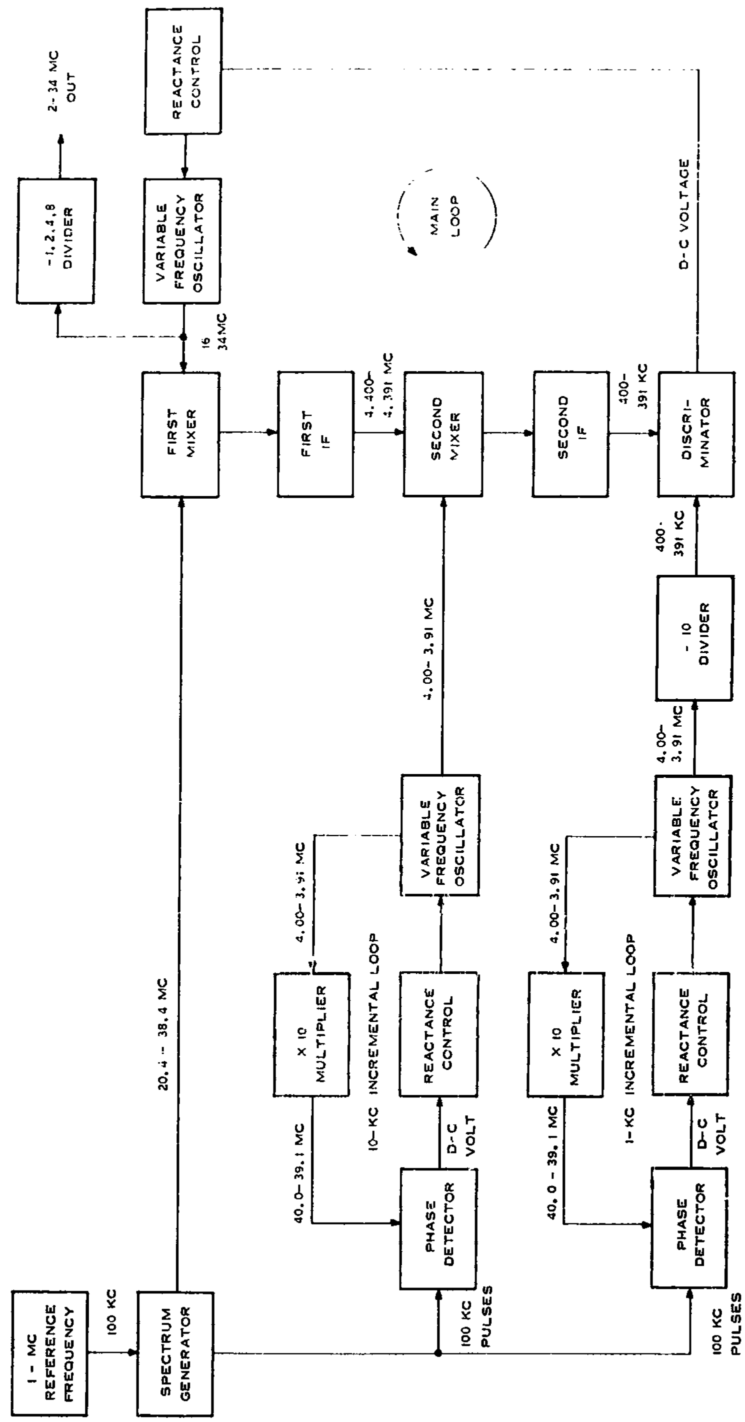


Fig. 7-6 Manson Synthesizer

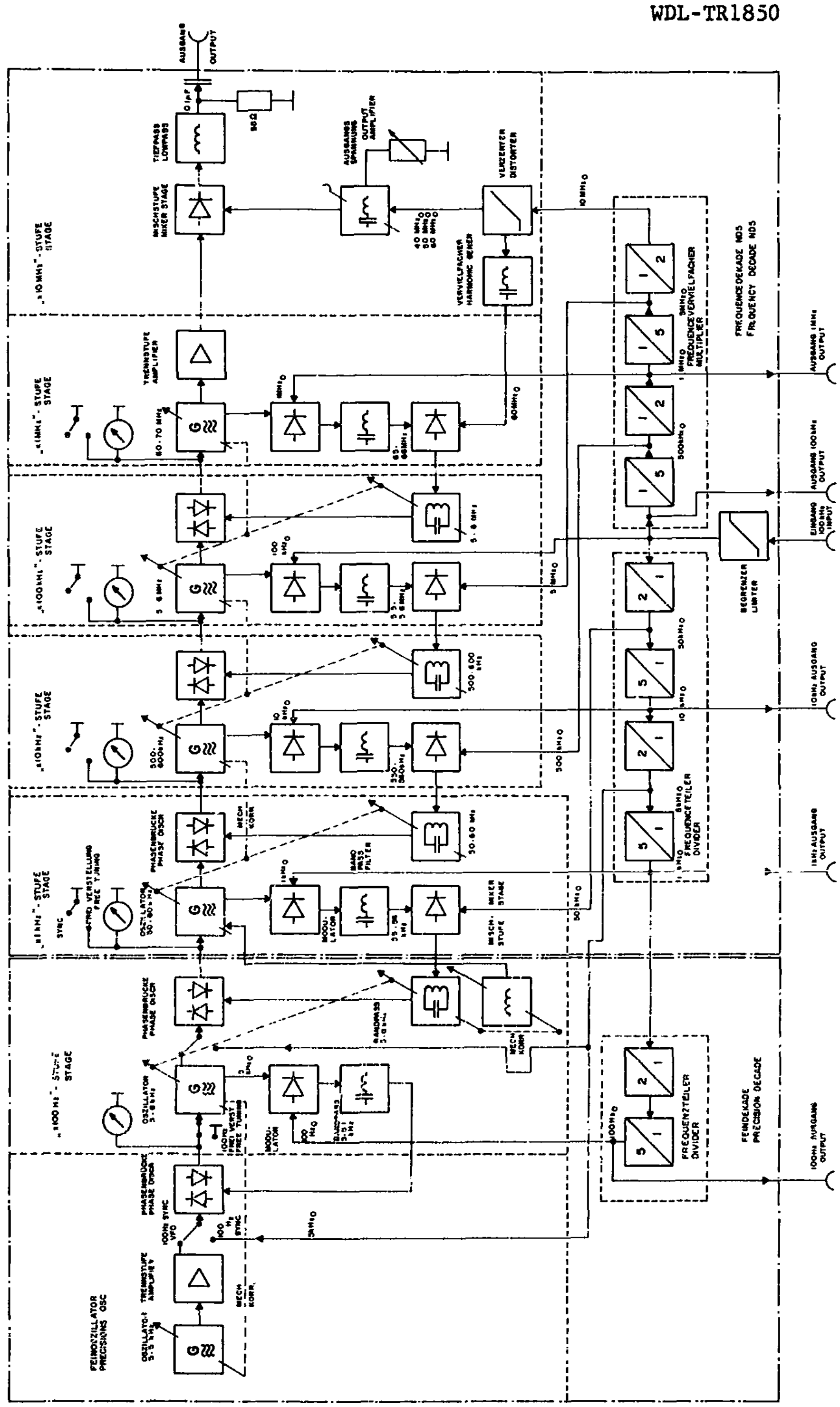


Fig. 7-7 Shomandl Synthesizer

7.4 MANSON SYNTHESIZER

The Manson synthesizer is a modified Plessey type. The main loop contains a reactance-controlled variable-frequency oscillator whose output frequency is controlled by the d-c voltage output of the discriminator within the loop. The main loop includes two mixer stages and two intermediate-frequency (I-F) stages which resemble a double-superheterodyne circuit. The output, instead of being a conventional audio signal, is a d-c voltage with an amplitude that is determined by the phase coincidence between the second I-F signal and the output of the 1-kc loop.

The outputs of the spectrum generator and the main-loop variable-frequency oscillator are mixed in the first mixer stage to produce a difference that is the first intermediate frequency. The output of the 10-kc incremental loop is mixed with the first I-F signal in the second mixer to produce a difference that is the second intermediate frequency. The second I-F is compared in the main-loop discriminator with the output of the 1-kc incremental loop.

The discriminator output disciplines the variable-frequency oscillator of the main-loop by locking it to the selected frequency.

The variable-frequency oscillators of the incremental loops are each disciplined through phase-detector stages by the 100-kc output pulses of the spectrum generator. As a consequency of the three loops, the output frequencies of the variable-frequency oscillator in the main loop are regulated at three points by signals that are derived from the single reference source.

7.5 RHODE AND SCHWARZ SYNTHESIZER

Figure 7-8 shows an example of a general purpose synthesizer which provides considerable flexibility of operation.

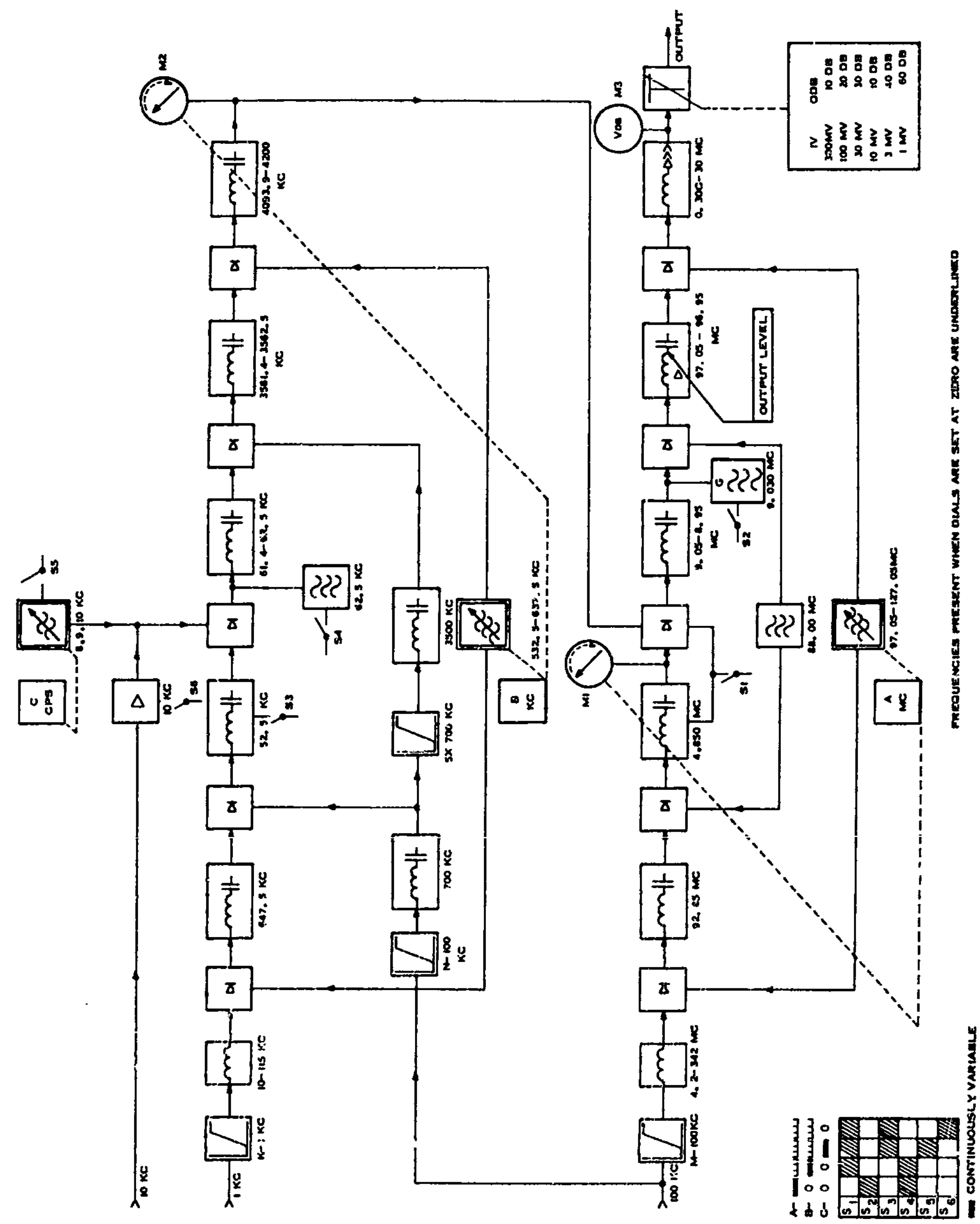


Fig. 7-8 Rohde Schwarz Synthesizer

Output frequencies of zero to 30 mc are provided. Output frequencies spaced 1-kc apart are synthesized from standard frequencies of 100 kc, 10 kc, and 1 kc, while an interpolation oscillator is provided to fill in between the steps. The desired output frequency is selected by three dials. Dial A selects the associated multiple of 100 kc, Dial B selects the 1 kc multiple, and Dial C selects the remaining cycles. The output frequency is therefore read directly as the sum of the settings of the three dials.

When the desired frequency is a multiple of 1 kc, the interpolation oscillator may be disengaged and the output frequency obtained with full accuracy of the standard frequency. If output frequency is to be continuously variable over a 100-kc range, the 1-kc selector may be unlocked from the standard frequency. The frequency may then be varied continuously with an accuracy of about 300 cps, while the Dial A remains on one of the locked settings. The 100-kc selector may be unlocked and the full range of output frequencies obtained continuously variable by Dial A. In this case the accuracy is about 30 kc.

High order harmonic generators are used to generate the harmonic spectrum of the 100-kc and 1-kc standard frequencies. The desired harmonics are selected from the spectrum generated by use of the drift cancelled oscillator system. Double conversion loops are used in order to obtain proper ratios of mixing frequencies. The frequency of the step selecting oscillators does not appear in the equation of the final synthesizer frequency because of the drift-cancel type of operation. The dials are calibrated in terms of output frequency and the selector dials are initially set to the desired frequency. Slight readjustment is usually necessary to center the harmonic frequency in the pass band of the filters. The bandwidth of the filters is less than the spacing between adjacent harmonics.

Continuously variable or stepped output frequencies are obtained by a combination of switches as shown by the chart on Fig. 7-8. For continuously variable operation the drift-cancelled loops are disengaged and auxiliary fixed frequency oscillators are switched in for mixing with the continuously variable step oscillators.

7.6 AN URT-2 TRANSMITTER

The block diagram of the synthesizer portion of the transmitter is shown in Fig. 7-9).

In this design, all frequencies are generated from a single 100-kc crystal, except for increments of less than 10 kc, which are provided from an interpolation oscillator. Calibration equipment for the interpolation oscillator is provided.

The output of the crystal oscillator is divided to 10 kc by a blocking oscillator, and multiplied to several integral megacycle frequencies in fixed-tuned frequency multipliers. The output of the 10-kc source and the 100-kc source are multiplied by factors ranging from 16 to 30 by impulse-governed oscillators. Channel selection is accomplished by adjusting the multiplication factor of these oscillators.

The output of the synthesizer is obtained by simply mixing of the various components of the desired frequency, and filtering the proper beat product from the mixers.

7.7 THE I.T.T. AND GENERAL RADIO SYNTHESIZERS

The I.T.T. and General Radio synthesizers (Fig. 7-10) are counter-type units. An oscillator is phase or frequency-locked through a variable scale of "N" divider. The pulse output of the divider is compared by coincidence methods with a pulse derived from a crystal oscillator.

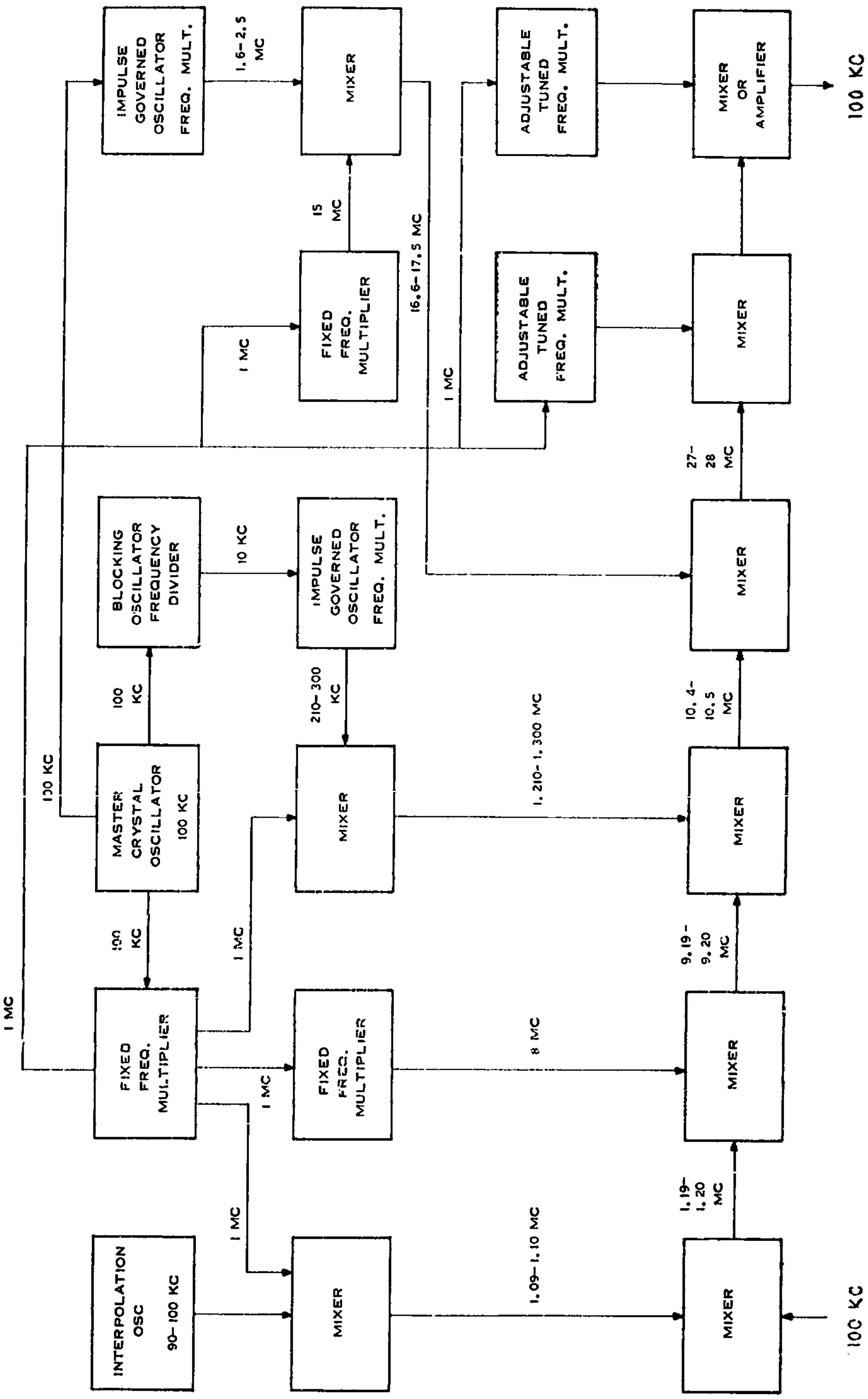


Fig. 7-9 AN/URT - 2 Synthesizer

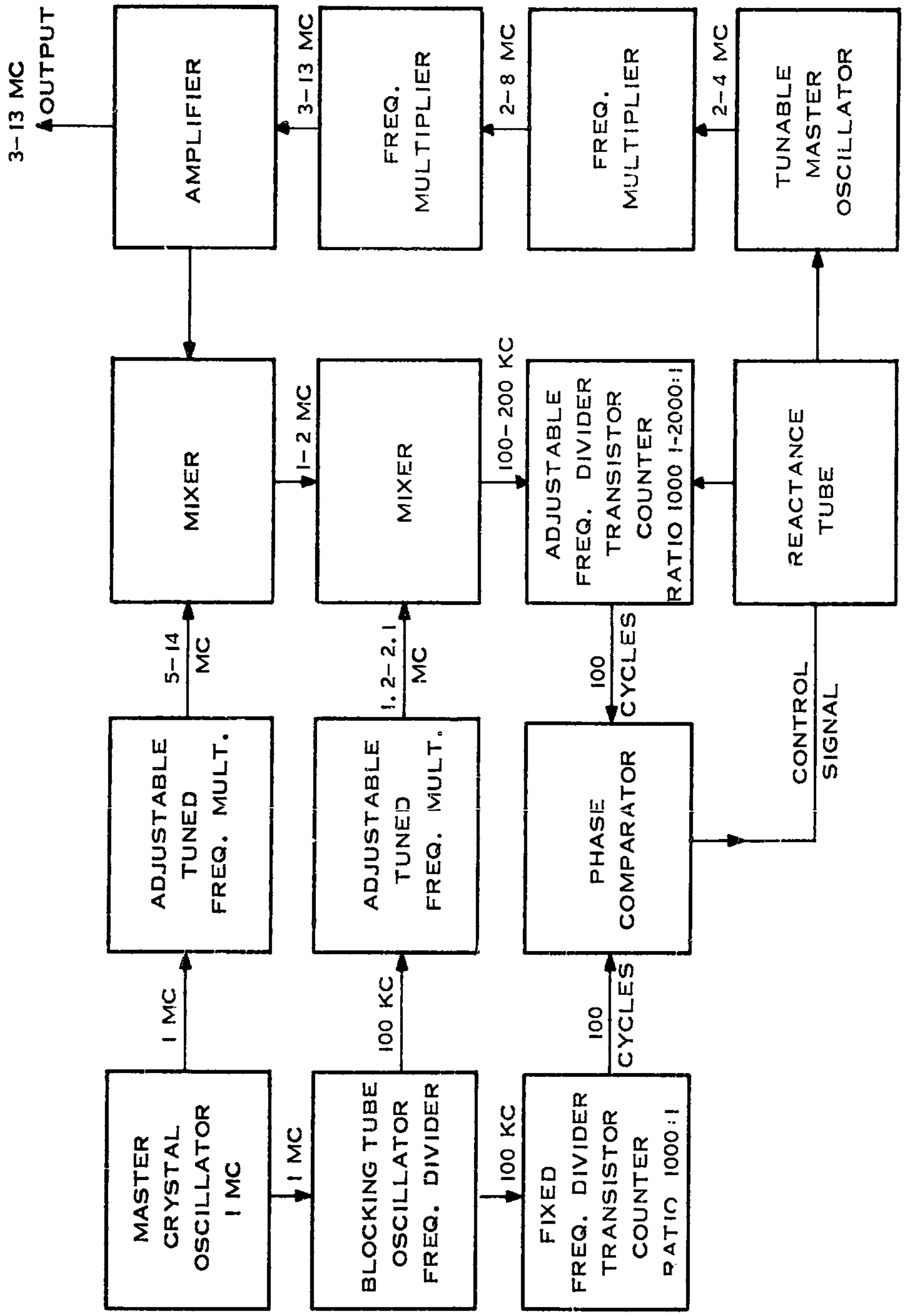


Fig 7-10 I.T.T. Synthesizer Controlled Oscillator System

Digital counters normally operate as frequency dividers. A single output pulse is generated each time the required number of input pulses has been counted. A wide variety of devices has been employed as counters, each marked by a significant upper frequency limit. Counting operations above one megacycle are difficult and above 10 mc are not commercially practical. One advantage of counters is that almost any integral division ratio may be obtained, and modification of this ratio by switches is possible. Although, through the use of binary circuitry, the reliability can be good, the phase jitter becomes appreciable. For the most part, this jitter amounts to 1×10^{-5}.

7.8 BINARY ANALOG SYSTEM

An analog binary system is extremely attractive because of the passive nature of the divide by two circuit or multiply by two. For example, if 1.754 is to be derived from 1 mc, the ratio 1.754 expressed to radix 2 is required. Although exact frequency synthesis may not always be possible, the resulting number can always be approximated to the desired accuracy. In actual use, multiplication and mixing are used to obtain the frequency synthesized number. Figure 7-11 serves as a simple example. To synthesize 287 mc from 1 mc, the procedure would be of the following form. The number 287 expressed in a binary number is 110001001. The block diagram of Fig. 7-11 shows how this is accomplished.

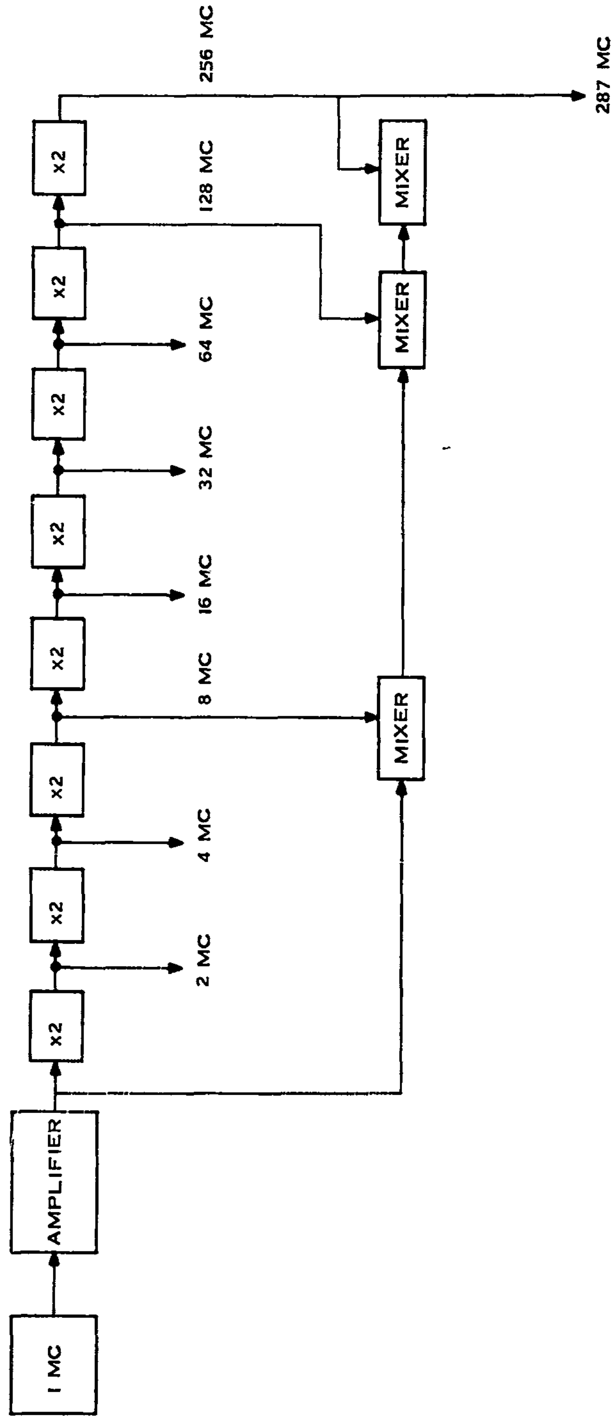


Fig. 7-11 Diagram of Binary Frequency Synthesizer

SECTION 8
I-F AMPLIFIERS

8.1 GENERAL DISCUSSION

In superheterodyne receivers, the I-F amplifier contributes the major part of the gain and determines the frequency response curve. In the multipurpose receiver, three types of I-F amplifiers are required.

1. Low Noise I-F Preamplifier
2. Wide-band First I-F Amplifier
3. Narrow-band Second I-F Amplifier

From the noise equation (5-1), it can be seen that the part of the noise figure contributed by the I-F amplifier is given by:

$$NF' = L_x (N_{IF} - 1) \qquad (8\text{-}1)$$

where

L_x = Mixer conversion loss

N_{IF} = I-F amplifier noise figure

It is obvious, then, that the I-F amplifier noise figure should be kept low. Furthermore, the noise figure of a multistage amplifier is determined mainly by the first stage. It is common practice to use an I-F preamplifier designed especially for a low noise figure, having enough gain to override the poorer noise figure of the main or wide-band I-F amplifier. The wide-band I-F amplifier, as described below, will have a bandwidth variable between 1 mc and30 mc, and will contribute the major part of the gain for the straight forward a-m or F-M operation. For bandwidths under 1 mc and for phase lock and frequency lock operation, double conversion will be used.

8.2 CHOICE OF INTERMEDIATE FREQUENCIES

The logical choice for the second I-F is 5.0 mc. One reason is that for the reference oscillator, this frequency is available directly from the high stability quartz oscillator that serves as the frequency standard for the whole receiver. Many phase detectors for phase-lock loops have also been developed at this frequency.

Several factors govern the chose of the first I-F.

a. The maximum bandwidth required for F-M detection with a discriminator is 30 mc. It is estimated that good discriminator linearity can be obtained when the center frequency is at least 65 mc.

b. The main I-F amplifier will be of the "wide-open" type utilizing line simulating transformers. The phase linearity will be good to about 100 mc. With this frequency representing the limit for the upper band edge of the 30-mc band, the first I-F center frequency should be under 100 - 30/2 = 85 mc.

c. In most cases, one will want the doppler frequency to have the proper sign (positive for approaching and negative for receding signal source). To achieve this, the LO frequency must be lower than the signal frequency. This means that for received frequencies from 100 mc to 500 mc, the first I-F must be lower than 50 mc. Otherwise the LO will tune through the I-F at some frequency, and in the worst case block the receiver, and in the best case a destorted signal will be produced. Therefore, for the lower signal frequencies, a first I-F as determined above can not be used.

d. The need for two different first I-F's is thus established and, therefore, two oscillator frequencies must be used to translate the first I-F signal down to the 5.0 mc second I-F.

It is possible, however, to make these two oscillator frequencies harmonically related so that only a single VCO will be required. When the lower first I-F is used the VCO feeds the second mixer directly; when the higher first I-F is used, a harmonic generator preferably consisting of balanced doublers is connected between the VCO and the mixer.

If extremely high VCO stability is required, (the tracking range will necessarily be narrow in this case), a crystal VCO should be used that uses a crystal operating in the fundamental series mode at a frequency under 20 mc.

It can be seen that all conditions set forth above are met with:

First IF for the lower frequency ranges	=	21 mc
First IF for the higher frequency ranges	=	69 mc
VCO frequency	=	16 mc
Multiplication in harmonic generator	=	4 times.

8.3 FIRST I-F AMPLIFIER, 21 MC AND 69 MC

The advancements in transistor and wide-band coupling element technology have made amplifiers possible with a frequency response having the - 3 db points at about 1 mc and 110 mc. Such amplifiers' are equipped with plug in bandpass filters centered around the desired frequency, either 21 mc or 69 mc. A single amplifier of this type can be used as the first I-F amplifier in the multipurpose receiver.

The coupling elements used will be "Line Simulating Transformers" which are described in the proceedings of the IRE, dated August 1959, (page 1337). Because the IRE article is detailed, only a very brief explanation of this coupling device will be given here.

Figure 8-1 illustrates a conventional transformer except that it is bifilarly wound and seems to have the secondary grounded in an unfamiliar manner. The reason is that this permits the figure shown

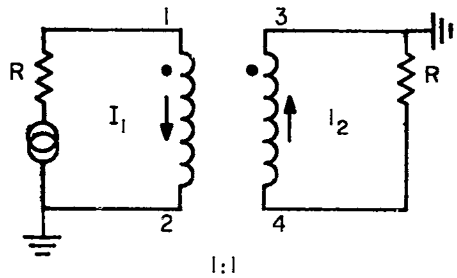


Fig. 8-1

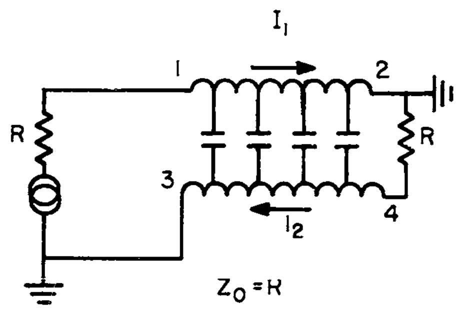


Fig 8-2

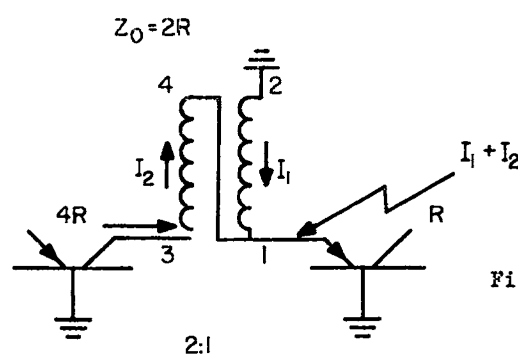


Fig 8-3

in Figure 8-2. Disregarding the primary magnetizing current (it is small compared to the load current), the two currents I_1 and I_2 are equal. These currents flow in opposite directions as shown, just as they would flow in a line loaded with the resistor R. The two bifilar windings of the transformer form a line that is twisted around the core. The stray capacities, which in ordinary transformers result in peaking of the response curve with a subsequent sharp drip, now form part of the line. For reflection free operation, the line should have a characteristic impedance $Z_o = R$.

An actual transistor stage configuration using a 2:1 step down transformer is shown in Figure 8-3. Disregarding the magnetizing current, $I_1 = I_2$, the transformer still simulates a line. The 2:1 step down ratio (4:1 impedance ratio) is close enough for the grounded base configuration. With the transistor close to 1.0, the stage gain will be 5 to 6 db. Feedback (not shown) will be used in each stage.

As shown in Figure 18-1, the first I-F amplifier is divided into modules having a gain of 25 to 30 db each. There are several reasons for this.

The method of obtaining AGC by varying the bias on the transistors will not be used in this receiver as this leads to difficulties with pole-shifting. Instead, voltage controlled attenuators will be introduced between modules in such a manner that none of the stages will operate too close to saturation over the required dynamic range.

The band setting filters can more conveniently be connected between I-F amplifier modules rather than inside the modules themselves. In this manner, standard and uniform modules are used and the required gain determines how many modules should be operated in cascade. The required maximum gain for the first I-F amplifier will vary with the different modes of operation. For instance when double conversion is used, only about 30-db gain is needed in the first I-F amplifier, so, in this case, a single module will be sufficient. The required gain for the single conversion a-m or F-M operation can be accurately calculated

only when the losses in the filters have been measured. An example of how the first I-F amplifier gain is calculated for the single conversion a-m case is shown below. The figures used for the losses are estimates and will change during the development phase.

Assumed conditions:

RF/IF bandwidth	1 mc
Presel. loss	2 db
Mixer loss	6 db
Pre I-F gain	30 db
I-F filter loss	6 db
AGC Netw. loss	6 db (at min. attenuation)

This then accounts for a net gain of 10 db.

With a noise figure of 10 db, the equivalent total input noise power level in 1-mc bandwidth is -104 dbm. For a predetection S/N ratio of 1.0, the minimum input signal level is thus -104 dbm. The minimum level at the detector should be about -10 dbm; a net gain of 94 db is required preceding the detector. The pre- IF gain minus losses (above) was 18 db so that in this case, the first IF gain must be about 76 db. This calls for three cascaded standard pre-IF modules.

8.4 I-F FILTERS

If high-pass and low-pass filters, both with adjustable cutoff frequencies in the range of 10 mc to 100 mc were available, the I-F amplifier just described would indeed be versatile. It could operate on any center frequency with any bandwidth within these frequency limits. Of course such filters are not available. With strict requirements to phase linearity and constancy of image impedance, their design would be extremely difficult, and, if feasible at all, the filters would probably be too complex and bulky.

Fortunately the requirements for I-F amplifiers in the multipurpose receiver are limited, permitting consideration of the varable cutoff high- and low-pass filters on a more realistic basis. The center frequency and bandwidth requirements for the first I-F amplifier are as follows:

I-F Center Frequency	Bandwidth
21 mc	1 to 5 mc
69 mc	1 to 30 mc

Now if one set of high-pass and one set of low-pass filters are used for each center frequency, the ranges for the adjustable cutoff frequency would be:

Filter Type		Cutoff Frequency Range
high-pass	1	18.5 to 21.0 mc
low-pass	1	21.0 to 23.5 mc
high-pass	2	54.0 to 68.5 mc
low-pass	2	69.5 to 84.0 mc

The maximum tuning range for the cutoff frequency is now about 25 percent. This also represents the amount of change required for each filter component, and is considered to be within the realm of feasibility. The response curve for the amplifier and the band-edges for the filters are illustrated by Figure 8-4.*

* The reason for using the M-derived end sections in the following figures is that the image impedance stays more constant through the pass-band than for the constant K-type. Also a sharper cutoff is obtained due to the two zeros just outside the band-edge.

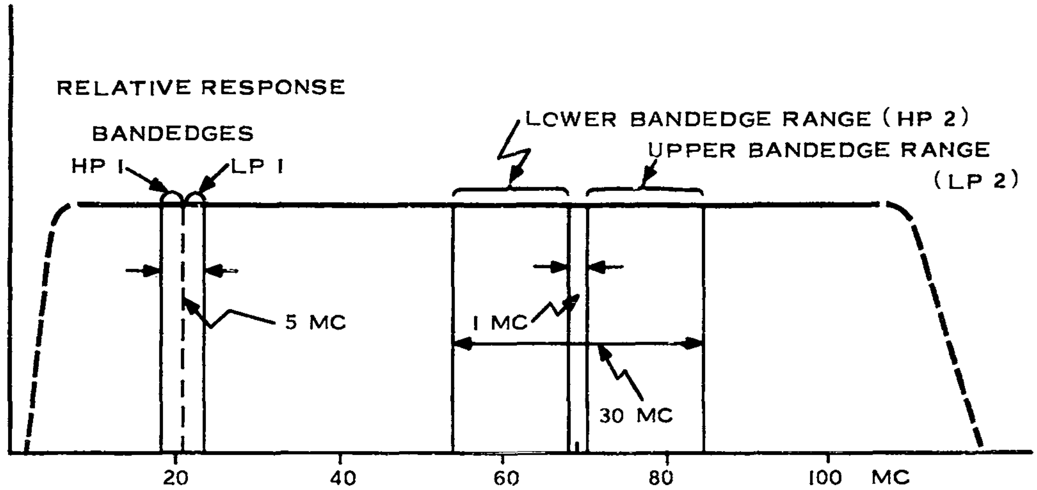


Fig. 8-4 Band-Edge Location

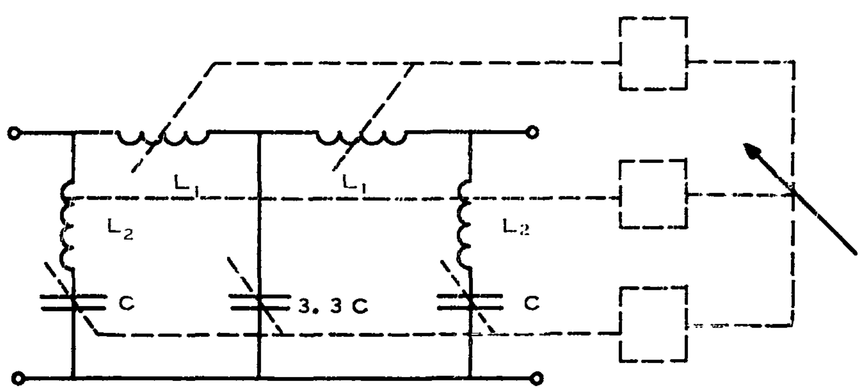


Fig. 8-4A Low-pass filter

An example of a low-pass filter is shown in Figure 8-4A. Time has not permitted calculations and design, so that actual filter may look different from the one shown. Filters in general have a number of components with identical values through the tuning band, and these can obviously be "ganged" together electrically or mechanically.

A low-pass filter of this type, designed for the 69-mc I-F, having an image impedance of 100 ohms would have four different component values with these ranges:

Cutoff Frequency	L_1	L_2	C	3.3 C
84 mc	0.3 Hy	0.16 Hy	11.5pF	38pF
69.5 mc	0.36 Hy	0.19 Hy	13.9pF	46pF

The high-pass filters will have similar ranges.

With the availability of voltage or current controlled tuning elements (varactors), electrical control of the bandwidths should be possible. The voltage controlled capacitors (Varicaps) have ranges and Q sufficiently high to be used directly. The current controlled inductors (Increductors) may be a little short on Q and generally requires high control power, up to 1 watt. However, this power can be reduced considerably with the greatly reduced tuning range required in this case. The Q can be improved by paralleling the increductor with a high Q coil. This would mean that a larger tuning range than listed above must be used, but according to the manufacturer (Trak Electronics Co.), a good compromise resulting in acceptable Q and control power can be worked out.

It is recommended that during the development phase high-pass and low-pass filters, utilizing Varicaps only, should be considered. If acceptable phase linearity can be obtained this way, it would definitely result in simpler filters with high reliability.

8.5 AGC ATTENUATORS

Automatic gain control in transistor amplifiers has always been quite a problem. The most straight forward method of controlling the gain of a transistor is to vary the base-to-emitter voltage. Unfortunately, sucy bias variation results in changes in the transistor parameters, which in turn cause detuning of the circuits. In this manner, the response curve and phase characteristic will change with applied AGC voltage. A circuit that overcomes this difficulty has been developed. It requires two transistors per stage operating in grounded emitter/grounded base configuration, and is actually the transistor equivalent of the "Cascode" circuit used for tubes. It is believed, however, that a better solution is to leave the active amplifier stages alone and perform the automatic gain control with voltage controlled passive attenuators between the amplifier modules. The attenuators consist of bridged T sections (for constant input and output impedance) where the resistors are replaced with forward biased diodes. The curved voltage/current characteristics of the semiconductor diodes result in a low impedance with high current and vice versa. To increase the attenuation, the current through the series diode is decreased and the current through the shunt diode is increased. The current is delivered by the AGC circuitry where the gain/signal level curve is controlled.

8.6 LIMITERS

Amplitude limiters are required ahead of the F-M detector to eliminate the effect of a-m caused by impulse noise satellite spin. For good discriminator "capture ratio", at least two stages of limiting should be used. The dynamic range need not be very great as the AGC will take care of signal strength variations. For the same reasons as mentioned above, the limiting action should not be based on bias changes. Instead the simple solution utilizing diodes as amplitude "clippers" is suggested. The microwave diodes type 1N83 should be ideally suited for this purpose, having only 0.5 to 1.0 pF capacity. Two of these connected in opposite directions across the wide-band

transformers should clip the amplitude at about 0.25 volts. The estimated impedance at this point is about 160 ohms so the power level will be limited to about 0.5 mw for the fundamental frequency. Two amplifier stages of the wide-band type will be required to boost this power to the 5-mw level required by the discriminator.

8.7 SECOND I-F AMPLIFIER, 5.0 MC

For narrow-band operation with bandwidths up to 1 mc, dual conversion is used. The second I-F amplifier will be similiar in design to the first I-F amplifier having a gain of about 120 db and a maximum bandwidth about 1 mc. For narrower bandwidths, plug-in filters requiring a special matching stage could be used. Crystal filters are frequently used for the narrowest bandwidths. AGC is performed by voltage controlled attenuators the same as for the first I-F amplifier.

8.8 VIDEO AMPLIFIERS

8.8.1 General

With the wide variety of signals to be amplified in the video amplifiers, resulting in varying requirements to bandwidth, input and output impedance, and drift, it will probably be impractical to try to design a single amplifier to do everything. At present it looks like three basically different amplifiers may be required.

8.8.2 Wide-band Amplifier

The input to the wide-band video amplifier will come from a conventional F-M discriminator or a-m detector. The input impedance should be highest possible compatible with the frequency response which should be flat from 50 cps to 10 mc.

The output impedance should be around 100 ohms so the amplifier can be used to drive a long transmission line of the coaxial type with some mismatch at the end. Reflections will be absorbed in this manner

(and "ghosts" will not appear, if a high resolution picture for instance is transmitted). The upper cutoff frequency should be adjustable in two equal logarithmic steps per decade (i.e. 33 kc, 100 kc, 330 kc, 1.0 mc,). The phase stability of the wide-band amplifier should be within ±3 degrees over the middle 60 percent of the frequency range.

The gain must be adjustable from 0 to 10 times and gain stability should be within ±0.1 db under all conditions. This amplifier is probably not available as an "off-the-shelf" item. Output voltage limits will be ±1.0 volt.

8.8.3 PAM/PCM Video Amplifier

This amplifier will be a narrower band version of the wide-band amplifier, but the frequency response in this case must go to dc. An upper frequency limit of 1.0 mc will probably be sufficient. Other requirements will be as described under 8.8.2 above. Again, development is probably required to produce this type amplifier.

8.8.4 Monopulse Servo Error Signal Amplifier

Two of these amplifiers are required when the receiver is used in an amplitude monopulse tracking system. They must be of the low drift type with frequency response from dc to 20 cps. Output impedance can probably be of the order of 1000 ohms. Other characteristics are similar to those required for the wideband amplifier.

There are a number of d-c amplifiers on the market that will meet these requirements.

SECTION 9
DETECTION METHODS INCLUDING FEEDBACK SYSTEMS

9.1 INTRODUCTION

The multipurpose receiver must be capable of detecting or demodulating all of the specific types of input signal modulations which include:

a. Amplitude
b. Wide- and Narrow-Band Angle
c. Continuous Carrier Tracking (CW)

Additionally, provision must be made for adaptations to specific requirements using matched filters or programmable local oscillators, e.g. frequency hopping or coded systems.

The receiver must be capable of operation at the narrowest (1 cps) and widest (100 mc) bandwidths that will be required of a communication system. Moreover, the signals must be detected with the highest signal-to-noise ratio (SNR) practicable without undesirable distortion, and at the lowest possible thresholds.

The solution to the detection problems is to use conventional detection techniques when maximum requirements are not placed on the threshold, the bandwidth, and the signal-to-noise ratio.

For the maximum requirements, phase and frequency lock feedback systems will be used. Phase lock will be used when frequency tracking requiring narrow-bandwidths (e.g. 1 cps) and when AM, PM, or FM modulations (modulation index less than one) are necessary. Frequency lock will be used when low FM thresholds or high FM improvements are needed and when large r-f bandwidths (e.g. 20 mc to 100 mc) are necessary such as might be needed in a communication satellite.

Automatic Frequency Control (AFC) will be needed for FM detection when the received signal does not have good frequency stability or when the doppler frequency change is very large. The AFC will keep the F-M signal in the center of the discriminator and I-F amplifier passbands.

The frequency feedback systems will require sweep acquisition circuitry to perform a need of automatic signal acquisition.

An automatic gain control (AGC) system will be needed with monopulse operation, A-M detection, and phase lock operation. Limiters are used to keep the signals constant in the FM and phase lock systems.

All of the above methods of detection and their associated feedback systems including AFC, AGC, and acquisition sweep circuits will be discussed in this section.

Double conversion will be used when the I-F bandwidth can be 1 mc and less and single conversion will be used when the I-F bandwidth needs to be larger than 1 mc. The maximum R-F bandwidth to be considered will be one per cent of the received frequency or 100 mc at 10 Gc.

9.2 STANDARD DETECTION

9.2.1 Amplitude Modulation

A standard amplitude modulation detector will be placed at the output of each I-F amplifier.

The definition of detector used here is a half wave linear device followed by a low pass filter.

Consider the effective bandwidth of the I-F amplifiers:

Amplifier	Center Frequency	Maximum Bandwidth
First	21 mc	5 mc
First	69 mc	30 mc
Second	5 mc	1 mc

It would be desirable to have the I-F frequency equal to 20 to 100 times the maximum modulating frequency.

This would mean that the highest modulating frequency could be:

I-F Center Frequency	Modulating Frequency (Max.)
21 mc	200 kc to 1 mc
69 mc	700 kc to 3.5 mc
5 mc	50 kc to 250 kc

For practical applications, the values shown should be an adequate safe maximum for the maximum modulating frequency when using amplitude modulation.

The carrier frequency should not appear in the detector output. Adequate attenuation of the carrier can be achieved by multiple pole filtering, by the use of traps tuned to the I-F frequency or by the use of a balanced detector.

For the practical situation, if the A-M detector requires tuned circuits, it might be well to eliminate the 21 mc requirements to limit the requirement to two A-M detectors, one for each I-F amplifier output.

It will be necessary to provide the A-M detector with a sufficient drive power of approximately -10 dbm. This fact will need to be accounted for since the I-F amplifier may have several outputs, some requiring different power levels.

9.2.2 Frequency Modulation

Standard F-M discriminators will be used for detection of F-M signals at the output of the first and second I-F amplifiers.

A discriminator will be placed at the output of each I-F amplifiers. One will be tuned to 5 mc with a 1-mc bandwidth and a sensitivity of one volt per 500 kc. Two will be tuned to 69 mc; one with a sensitivity of one volt per 10 mc and the other with a sensitivity of one volt per 5 mc. The bandwidths of these discriminators will be 20-mc and 10-mc minimum respectively. Other discriminators including a 30 mc one at 69 mc, and one at 21 mc will be available as plug-in units when they are needed. For bandwidths wider than 20 mc, frequency lock can be used which will compress the wide R-F bandwidth to less than 20 mc. The 21 mc I-F amplifier is used at input signal frequencies often less than 500 mc having a maximum R-F bandwidth of less than 5 mc. For these cases, the maximum modulating frequency will not be larger than 500 kc allowing the use of double conversion.

These same frequency discriminators can be used for frequency lock.

A limiter will be placed in front of each discriminator to reduce the effects of amplitude variations in the signal and to reduce the power level of the noise before the discriminator.

The input signal power level to the frequency discriminators will need to be about 0 dbm.

The F-M detection system will need to employ AFC for drifting input signal frequencies. AFC will be discussed in a later paragraph.

9.3 PHASE LOCK

9.3.1 General

Phase lock, narrow-band frequency tracking filters are used in space communication systems for three important application. One is to provide a reference carrier for doppler frequency measurements, the second is to provide a reference carrier for monopulse error channel receivers, and the third is to provide detection of amplitude or low index angle modulated signals. Phase lock is used when other detection techniques can not be provided with a low enough pre-detection noise bandwidth to obtain an adequate signal-to-noise ratio on the reference carrier frequency signal.

The phase lock loop must operate at radio frequencies from 100 mc to 10 Gc with noise bandwidths down to 1 cps. The lowest bandwidth that can be used depends upon several factors, such as receiver local or transmitter oscillator instabilities cause transient errors within the phase lock loop. These transient errors, when large enough, will cause the phase lock loop to lose lock or synchronism. Transient errors will occur as a result of changes of the input signal phase caused by radial range accelerations of the space vehicle. The magnitude of these transient errors are directly proportional to the oscillator instability and range acceleration and inversely proportional to the square of the loop noise bandwidth.

Another consideration depends upon the design of the voltage controlled oscillator (and transmitter oscillator). In order to achieve very high frequency stabilities, the maximum frequency deviation permitted for the oscillator is very low. Quantitatively, the above design problem areas can be summarized for a 2 Gc input signal and a 1.0 cps noise bandwidth.

In order to achieve a highly stabilized VCO of 4×10^{-11} per second, necessary to limit the transient error to an acceptable value, the frequency deviation of the oscillator must be limited to approximately ± 100 cps referenced to 20 mc for a 2 Gc input signal frequency. Further, the doppler frequency deviation and the range acceleration limit the minimum earth satellite altitude to approximately 10,000 nautical miles.

In the design of the phase-lock loop several factors must be considered. The output signal of a 20 mc VCO will need to be multiplied in frequency to reach the necessary local oscillator frequency. For the different frequency bands, the magnitude of the multiplier and the LO (VCO) frequency deviation will be proportional to the input signal frequency. This total frequency deviation must be equal to the total doppler frequency range. The LO or VCO center frequency must be set on the nominal value of the transmitter frequency. This can be accomplished by tuning the frequency synthesizer. In order to achieve adequate frequency deviation on the stable VCO, the VCO must be used for the first mixer local oscillator. For lower altitude satellites, altitude 100 to 10,000 nautical miles, the frequency deviation of the VCO must be greatly increased over the one specified above. This is accomplished at the expense of increased frequency instability.

A less stable crystal VCO can be used as the first mixer local oscillator or an L-C oscillator can be used as either of the mixer local oscillators. A suitable choice must be made. All oscillators will require ovens. The trade-offs are summarized in Table 9-1.

From Table 9-1, the L-C oscillator is the better choice with the operation to the second mixer. The biggest factors that sway the choice are that the second mixer LO multiplier chain is much shorter (e.g. 4 versus 128) than that needed for the second mixer and that the phase-lock loop gain is constant when the R-F bands and LO multipliers are switched.

TABLE 9-1

Consideration	First Mixer Crystal Oscillator	Second Mixer L-C Oscillator	First Mixer L-C Oscillator
Phase Lock Gain	Changes with Multiplier	Constant	Changes with Multiplier
Circuitry in Loop	Maximum	Minimum	Maximum
Test Loop without R-F Head	No	Yes	No
High K_v Constant	No	Yes	Yes
Operate with Frequency Lock	Yes	Yes	Yes
Frequency Lock Gain	Changes with Multiplier	Constant	Changes with Multiplier
Loop Gain Potential	Minimum	Minimum	Maximum
Shorter Multiplier Chain	No	Yes	No

The lowest bandwidth achievable with the L-C VCO at 2 Gc will be approximately 100 cps. The highest bandwidth needed for phase lock will depend largely on the shortest acquisition time needed. Practical upper limits on the bandwidth will be approximately 1000 cps to 3000 cps due to I-F bandwidth filter pole considerations related to loop stability (Nyquist).

In summary, a highly stable crystal controlled VCO will be used as the first mixer LO with noise bandwidths from 1 cps to 100 cps and an L-C oscillator will be used as the second mixer LO with noise bandwidths from 100 cps to 3000 cps.

9.3.2 VCO at First Mixer

The block diagram of the phase lock loop with the VCO at the first mixer is shown in Fig. 9-1. A stable local oscillator (STALO)

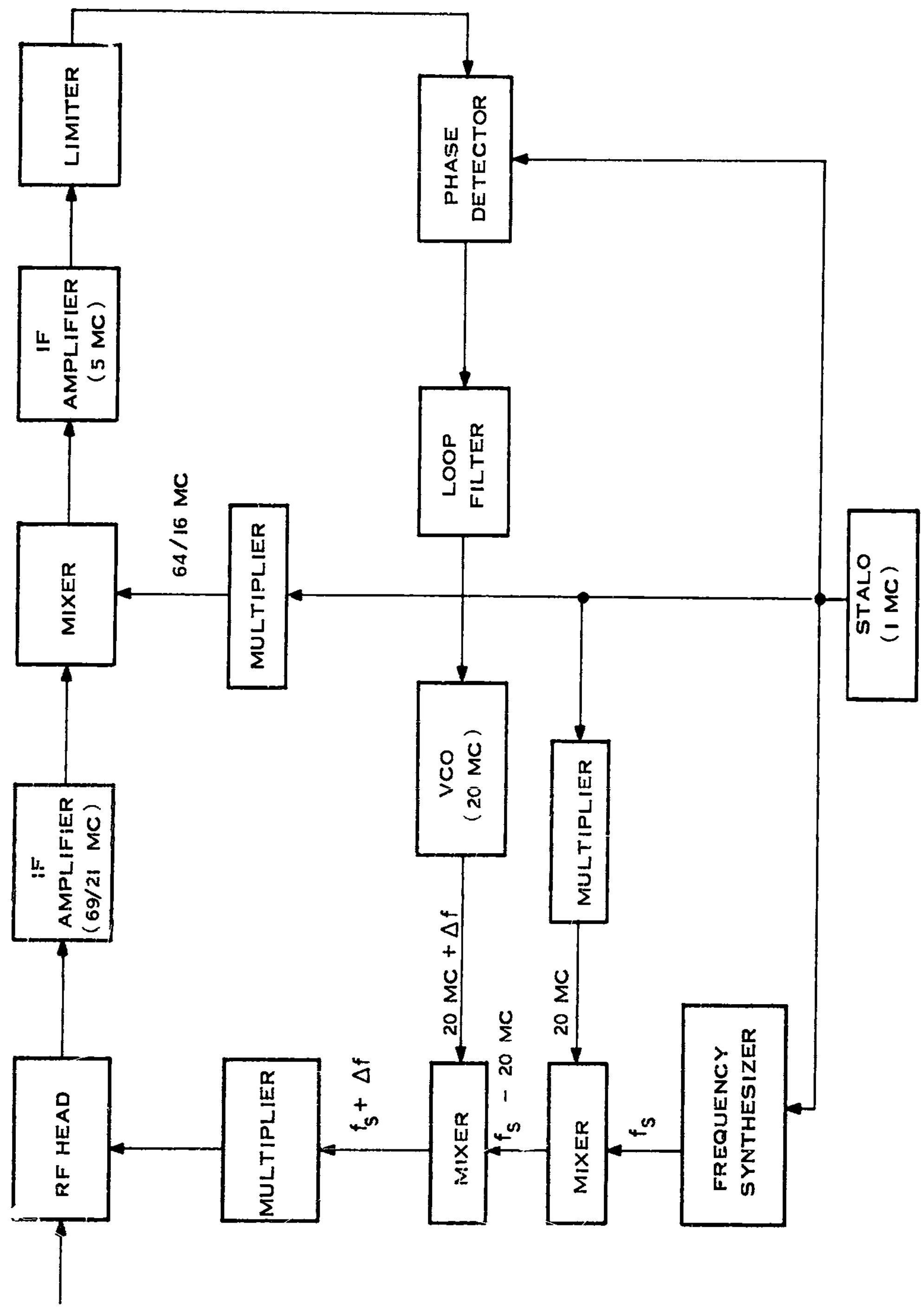


Fig. 9-1 Phase-Lock Loop with VCO at Second Mixer

is the reference oscillator for the phase detector, second local oscillator and frequency synthesizer. The frequency synthesizer output is mixed with the VCO output to form the LO signal fed to the harmonic generator multipliers. The harmonic generators feed the R-F head. The first and second I-F amplifiers are contained inside the loop. The signal will always remain in the center of the I-F amplifiers when the loop is in lock with drift from the center frequency equal to any drift in the STALO phase detector reference.

The major requirements for this phase-lock loop is that the noise bandwidth be as low as 1 cps. The VCO to meet this requirement can have a maximum frequency instability given as follows:

$$\text{Instability} = \frac{0.15(2B_L)}{f_o} \text{ per second} \tag{9-1}$$

$$= 7.5 \times 10^{-11} \text{ per second} \tag{9-2}$$

$$\text{Where } 2B_L = 1 \text{ cps}$$

$$f_o = 2 \text{ Gc}$$

This is the instability requirement for the space vehicle <u>transmitter</u> <u>oscillator</u> and the STALO in the receiver. This points out a reason that a phase coherent space vehicle transponder (all local oscillators including transmitter oscillator are derived from a <u>single</u> VCO phase locked to the input signal) is very often used when narrow bandwidths are required.

The above instability requirement is a rather pressing demand on the state-of-the-art for crystal controlled VCO's and STALO's. It seems possible that the lowest useable noise bandwidths ($2B_L$) are in the range of 1, 3, and 10 cps.

The foregoing has demonstrated that one of the elements in a phase-lock loop necessary to obtain narrow bandwidths is a very stable VCO and transmitter oscillators. A few of the design considerations for a stable oscillator are summarized as follows:

a. Selection of circuit e.g. modified Colpitts or Clapp crystal oscillator
b. Operation at close to the crystal frequency
c. Rigid mechanical support of components
d. Low stray capacities
e. Careful selection of crystals
f. Shock and vibration mounting
g. Entire oscillator mounted within a proportional oven
h. Well regulated power supply voltage
i. Small frequency deviation
j. Low drive and good AGC
k. Low overall power consumption.

Experience has shown that stable crystal oscillators can be designed in the frequency range 15 to 35 mc. For this report, the selection of the operating frequency will be 20 mc. This frequency was chosen because the bias frequency necessary for operation of the frequency synthesizer could be easily generated from a 1 mc or 5 mc STALO. (To avoid changing the operator control and display program for the frequency synthesizer when adding a 20 mc VCO frequency, a STALO bias frequency of 20 mc must be subtracted.)

The maximum deviation in a good stable VCO is difficult to determine without much experimentation, but it is estimated to be of the order of ± 100 cps at the oscillator frequency ($\pm$ 5 x 10^{-6} percent deviation). The frequency deviation available in each band is shown in Table 9-2. The resolution of the frequency synthesizer is also shown. The synthesizer of course must have sufficient resolution to place the tracking range of the phase-lock loop about the incoming frequency. It would be desireable to have the resolution of the

synthesizer about 10 per cent of the tracking range. In the example shown it is 19.4 per cent. This is a good compromise since the next step in the synthesizer resolution is 1.94 per cent or a resolution of 1×10^{-7}.

TABLE 9-2

Band	Multiplier	Deviation	Synthesizer Resolution
	(units)	(Kc)	(Kc)
1	256	$\pm$ 25.6	10
2	128	$\pm$ 12.8	5
3	64	$\pm$ 6.4	2.5
4	32	$\pm$ 3.2	1.25
5	16	$\pm$ 1.6	0.625
6	8	$\pm$ 0.8	0.3125
7	4	$\pm$ 0.4	0.15625

The time constant for the loop filter is required to be:

$$R_1C = 14.1 \frac{\Delta f}{(2B_L)\ 2} \tag{9-3}$$

$$R_1C = 3.6 \times 10^5 \text{ seconds} \tag{9-4}$$

$$\text{when } \Delta f = 25.6 \text{ kc}$$

$$2B_L = 1 \text{ cps}$$

The open loop gain is required to be:

$$NK_v\ K_m = 2.47 \times 10^{-3}\ R_1C\ (2B_L)^2$$

$$NK_v\ K_m = 8.9 \times 10^2$$

$$\text{when } R_1C = 3.6 \times 10^5 \text{ seconds.}$$

$2B_L$ = 1 cps

N = units

K_v = cps/volt

K_m = volts/degree

For the phase stable VCO, K_v will be of the order of 100 cps/volt. The appropriate value for K_m will then be for N = 256:

$$K_m = \frac{N K_v K_m}{NK_v} \tag{9-5}$$

$$K_m = 3.5 \times 10^{-2} \text{ volts/degree} \tag{9-6}$$

The above represents a suitable design for 10 Gc, but the lower frequency bands will require special consideration. Using the above formulas several results are summarized in Table 9-3 for a 1 cps noise bandwidth.

TABLE 9-3

Band	Deviation (Kc)	N (units)	R_1C (seconds)	$N K_v K_m$ (cps/degree)	$K_v K_m$ (cps/degree
1	$\pm$25.6	256	3.6×10^5	8.9×10^2	3.5
2	$\pm$12.8	128	1.8×10^5	4.45×10^2	3.5
3	$\pm$ 6.4	64	9.0×10^4	2.225×10^2	3.5
4	$\pm$ 3.2	32	4.5×10^4	1.11×10^2	3.5
5	$\pm$ 1.6	16	2.25×10^4	5.56×10^1	3.5
6	$\pm$ 0.8	8	1.125×10^4	2.78×10^1	3.5
7	$\pm$ 0.4	4	5.625×10^3	1.39×10^1	3.5

From Table 9-3, it can be noted that the deviation, multiplier, and the loop time constant change when the band is changed. Fortunately, the gain constants of the VCO and phase detector will remain constant. The result being that as the bands are switched, the time constant will also have to be switched keeping the noise bandwidth a constant. Of course the noise bandwidth will have to be changed, and, for each bandwidth, a set of time constants as a function of the band will also require switching.

An alternate solution if there were excessive $K_v K_m$ loop gain, would be to use the maximum value of $K_m K_v$ at the VHF Band (N = 4) and add simple resistor attenuators as the higher bands are used (N increases). But this is not the case.

The phase detector will be used with phase lock at the second mixer when wider deviations and larger noise bandwidths are needed. It would be desirable to have the same phase detector gain for each loop. This must be kept in mind when designing the phase-lock loop operating at the second mixer.

The next consideration is the configuration of the loop filter. The requirement of R_1C equaling 3.6×10^5 seconds is a rather stiff one using a totally passive filter. The required filter will be a lag filter since a perfect integrator cannot be realized. See Fig. 9-2 for a description of the loop filters.

Consider first the passive filter. If R_1 is chosen as 10 megohms. This is about a maximum value considering the parallel effects of R_L and R_3. The value of C would then need to be:

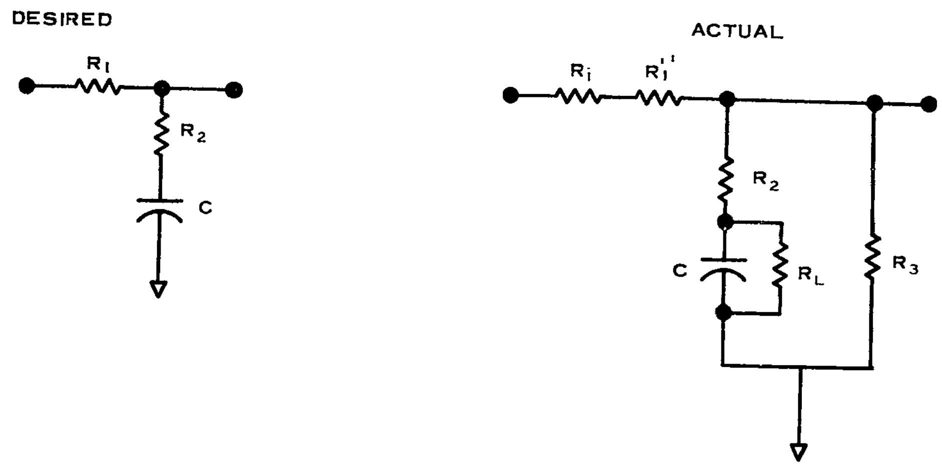
$$C = \frac{R_1 C}{R_1} \qquad (9\text{-}7)$$

$$C = 3.6 \times 10^{-2} \text{ farads} \qquad (9\text{-}8)$$

when $R_1C = 3.6 \times 10^5$ seconds.

$R_1 = 10^7$ ohms.

PASSIVE FILTER



$R_1 \ll R_L /\!/ R_3$
$R'_i \ll R_i$
$R_I \approx R_1$

$R_I = R_i + R'_i$
$R_3 =$ VCO LOAD RESISTANCE
$R_i =$ PHASE DETECTOR OUTPUT RESISTANCE
$R_L =$ CAPACITOR LEAKAGE RESISTANCE

ACTIVE FILTER

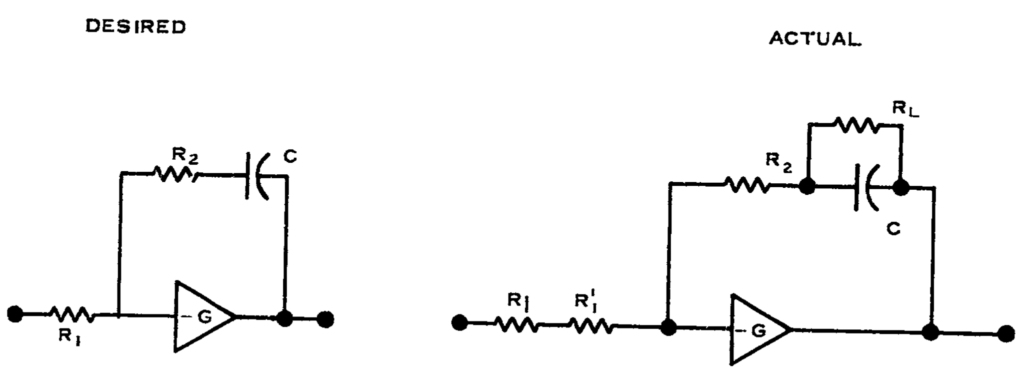


Fig. 9-2 Phase-Lock Loop Filters

This is too large a capacitor physically to be used in the receiver. Therefore the active filter must be used.

The transfer function for the (actual) active filter is:

$$F(S) = \frac{-R_2}{R_1} \quad \frac{S + a}{S + b} \tag{9-9}$$

$$\text{Where} \quad a = \frac{1}{CR_2}$$

$$b = \frac{1}{C(R_L \| GR_1)}$$

First assume $R_L \gg GR_1$. This is a good assumption since high quality capacitors are available with R_LC equal to 10^6 megohm-microfarads.

Then:

$$GR_1C = 3.6 \times 10^5 \text{ seconds} \tag{9-10}$$

Maximizing R_1 at about 10^7 ohms, there appears to be a choice for the values of G and C. The choice will depend upon the resulting physical sizes of the capacitor and the amplifier and whether the amplifier can be designed reasonably. One set of reasonable values would be:

C = 25 microfarads

G = 1000

R_1 = 15 megohms.

For $R_L \gg GR_1$, R_L must be greater than 1.5×10^6 megohms. For C equal to 25 microfarads, R_LC equals 3.6×10^6 megohm-microfarads. The assumption of $R_L \gg GR_1$ is not valid, and the parallel combination of R_L and GR_1 must be considered. The upper value on a transistor

amplifier gain is about 1000. If the value of C is increased to 50 microfarads, the parallel value of R_L and GR_1 must be 7.5 megohms and R_L must be equal to or greater than $10^3 \times 15 \times 10^6 = 1.5 \times 10^4$ megohms. The time constant of the capacitor would then need to be at least 1.5 $\times 10^4$ megohms x 25 microfarads or 3.6×10^5 megohm-microfarads. This requirement will require a high quality capacitor which will be fairly large physically. (It could be mounted between the feedback and I-F receiver chassis in the basic multipurpose receiver chassis drawer).

It must be noted that this loop design is shown for an input frequency of 10 Gc. At lower maximum input frequencies where the multiplier can be reduced, lesser requirements will be placed on the loop design.

The filter amplifier bandwidth must have a value of five times the maximum noise bandwidth for a conservative design. For a maximum noise bandwidth of 100 cps, the amplifier 3db bandwidth would be about 500 cps.

The I-F bandwidth configuration must be chosen wisely so the I-F amplifier will not greatly influence the design of the phase-lock loop. For a conservative design, the I-F bandwidth would be greater than 1000 cps for a two pole filter or 500 cps for a single pole filter for a loop noise bandwidth of 100 cps. (If the I-F bandwidth becomes too narrow, there can be danger of the loop oscillating).

A summary of loop parameters are shown in Table 9-4 noting that:

$$R_2 = \frac{1.5}{C(2B_L)} \tag{9-11}$$

and

$$D_1 = 0.071\ (2B_L)^2 \tag{9-12}$$

where D_1 = Maximum tracking rate in cps/s

The noise bandwidths selected are for 5 db steps or mainly 1, 3, 10, 30, and 100 cps.

TABLE 9-4

K_m = 35 mv/deg. K_v = 100 cps/volt.					
$2B_L$ (cps)	R_1(effective) (ohms)	R_2 (ohms)	C (microfards)	R_1C (seconds)	D_1 (cps/s)
1	7.5×10^9	3×10^4	. 50	3.6×10^5	7.1×10^{-2}
3	7.5×10^8	9.5×10^3	50	3.6×10^4	7.1×10^{-1}
10	7.5×10^4	3×10^3	50	3.6×10^3	7.1×10^o
30	7.5×10^6	9.5×10^2	50	3.6×10^2	7.1×10^1
100	7.5×10^5	3×10^2	50	3.6×10^1	7.1×10^2

R_1 effective $= \dfrac{R_L\ GR_1}{R_L + GR_1}$ $G = 10^3$

NOTE: R_1 will need to be switched when switching R-F Bands and multipliers.

9.3.3 VCO at Second Mixer

The block diagram of the phase-lock loop with the VCO at the second mixer is shown in Fig. 9-3. A STALO is the reference oscillator for the phase detector and frequency synthesizer. The frequency synthesizer tunes the receiver to the center of the tracking range of the phase-lock loop. In this case, only the second I-F amplifier is contained within the phase-lock loop.

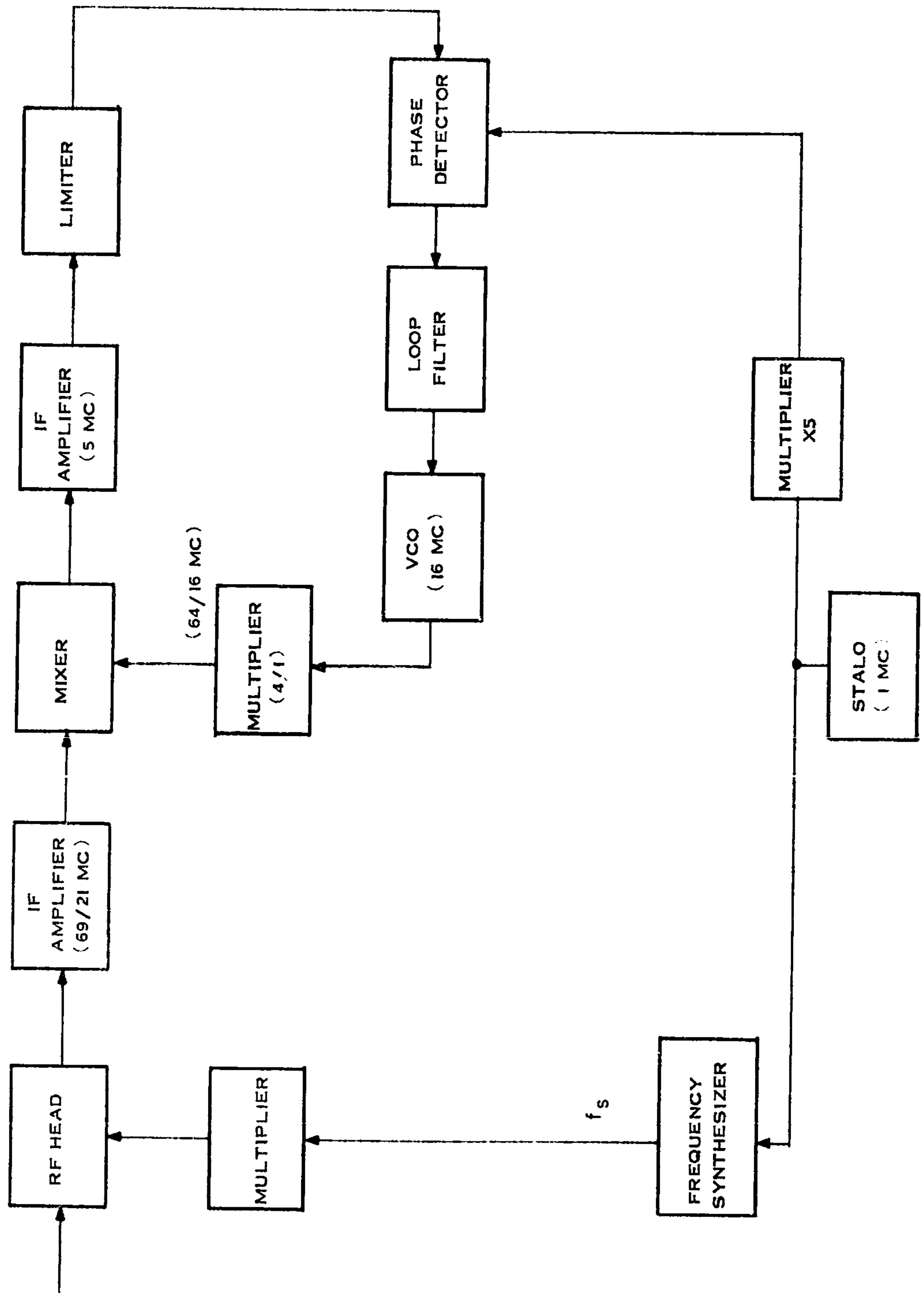


Fig. 9-3 Functional Diagram of Phase-Lock Loop with VCO at First Mixer

It is desirable to share the VCO for this phase-lock loop with the one at the second mixer for the frequency lock loop. For phase lock, the instability of the VCO cannot exceed:

$$\text{Instability} = \frac{0.15\ (2B_L)}{f_o} \text{ per second} \qquad (9\text{-}13)$$

$$= 2.3 \times 10^{-7} \text{ per second} \qquad (9\text{-}14)$$

where $2B_L = 100$ cps

$f_o = 64$ mc.

This is the instability requirement for the VCO. The instability requirement for the transmitter oscillator at 2 Gc is more rigid (using Equation 9-1):

$$\text{Instability} = 7.5 \times 10^{-9} \text{ per second} \qquad (9\text{-}15)$$

when $2B_L = 100$ cps

$f_o = 2$ Gc.

Since the long term instability of an oscillator is about one to two orders of magnitude poorer, this would mean the instability per day of the VCO could be 2×10^{-5} and of the transmitter oscillator could be 7.5×10^{-7}.

Experience at Philco shows that a carefully designed L-C oscillator will meet the above instability requirements and could have the following characteristics:

$K_v = 125\ K_c$/volt
$f_o = 16$ mc.
Deviation = $\pm$ 4 percent
Bandwidth = $\pm$ 10 percent
Linearity = 1 percent (slope change)

Position of poles at approximately 30 mc.
Instability = 1×10^{-6} standard item
= 1×10^{-7} careful design

The tracking range that should satisfy any requirement is $\pm$ 500 K_c. The loop time constant for a 100 cps noise bandwidth ($2B_L$) is:

$$R_1C = 14.1 \frac{\Delta f}{(2B_L)^2} \tag{9-16}$$

$$R_1C = 7 \times 10^2 \text{ seconds} \tag{9-17}$$

Similar results for 5 db steps in bandwidth are shown in Table 9-5.

TABLE 9-5

$2B_L$ (cps)	R_1C (seconds)	Minimum B_{I-F} (single pole) (cps)
100	7×10^2	400
300	7×10^1	1200
1000	7×10^0	4000
3000	7×10^{-1}	12000

The minimum I-F bandwidth for a single pole filter is also shown in Table 9-5. For multiple pole filters, the I-F bandwidth will have to be wider.

The open loop gain is required to be:

$$NK_vK_m = 2.47 \times 10^{-3} R_1C (2B_L)^2 \tag{9-18}$$

$$NK_vK_m = 1.73 \times 10^4 \tag{9-19}$$

when $R_1C = 7 \times 10^2$ seconds

$2B_L = 100$ cps

Then $K_m = 35$ mv/degree for $N = 4$. $N = 4$ when using the 69-mc I-F frequency. $N = 1$ when using the 21-mc. I-F frequency. At the lower I-F frequencies where 21 mc is used, it is legitimate to assume that the tracking range can be reduced. For the case at hand, it will be reduced by a factor of 4 to $\pm$ 125 kc. The time constant R_1C can then be reduced by a factor of 4 by changing R_1. This must be done for each noise bandwidth when switching between the 69-mc and 21-mc I-F frequencies.

It might be noted that 35 mv/degree is the same phase detector gain constant used in the loop to the first mixer.

It is desirable to use an active filter for the loop filter to keep the physical size to a minimum. For example, for a loop constant lag filter, if $R_1 = 10$ megohms, then $C = 70$ microfarads. This capacitor value could, of course, be used but the load impedance on the filter must be over 100 megohms. Using an operational amplifier and assuming $R_L \gg GR_1$ and $R_1 = 7$ megohms, then C could be as low as 1.0 microfarad for an amplifier gain of 100. When the maximum noise bandwidth is 3000 cps, the amplifier bandwidth should be greater than 15 kc.

A summary of the loop parameters for the phase lock loop with operation to the second mixer is shown in Table 9-6.

TABLE 9-6

LOOP PARAMETERS FOR SECOND MIXER

K_m = 35 mv/deg - K_v = 125 Kc/volt					
$2B_L$ (cps)	R_1 (ohms)	R_2 (ohms)	C (microfarads)	R_1C (seconds)	D_1 (cps/s)
100	7×10^6	1.5×10^4	1.0	7×10^2	7.1×10^2
300	7×10^5	4.7×10^3	1.0	7×10^1	7.1×10^3
1000	7×10^4	1.5×10^3	1.0	7×10^0	7.1×10^4
3000	7×10^3	4.7×10^2	1.0	7×10^1	7.1×10^5
Note - when using the 21 mc I-F, the value of R_1 must be reduced by 4.					

9.3.4 Phase Lock Considerations

Limiters vs. AGC. The phase-lock loop designs shown previously should apply to the lowest SNR within the loop noise bandwidth which is SNR equal to 0 db. The SNR is 4.5 db when the loop remains in lock at least 99 per cent of the time when the damping is 0.7071.

The phase detector operation is such that the gain changes if the input signal level changes and the loop gain and bandwidth will also change. If the loop is designed for a damping of 0.7071 at threshold (SNR = 0 db) signal level changes will cause the loop bandwidth to increase.

At threshold, the lowest phase-lock noise bandwidth is needed. At higher signal levels, the bandwidth could increase and such an increase would reduce transient errors. The bandwidth increases slower than the signal increases, and therefore the SNR will increase as the bandwidth increases. The higher the bandwidth also the larger the tracking range.

It is therefore desirable to have larger bandwidths at higher signal levels to reduce the transient response and increase the tracking range as the SNR is increasing. This is exactly what will happen with a hard limiter (limits on noise without signal) preceding the phase detector. The phase-lock loop will behave as an adaptive servo as a function of signal strength until full limiting occurs (I-F SNR $\approx$ 15 db).

Using AGC the gain and bandwidth of the phase-lock servo will remain nearly constant as the signal level changes from low to high values. At high signal levels, the transient errors are much higher than when using a limiter and the loop does not have optimum operation.

Limiters are therefore preferred over AGC systems. A combination of AGC and limiter operation however will produce the best system. Assuming that the minimum I-F SNR is -25 db, the limiter in order to limit on signal without noise (high signal levels) must have 25 db gain following the point where the AGC is taken off the I-F amplifier. The limiter will then require a 35 to 40 db gain. The AGC system will limit the maximum signal level input to the limiters. AGC is needed for monopulse operation, for signal strength indications at all signal levels, and for detection of amplitude modulated signals.

<u>Detection of PM, FM, and AM Signals</u>. For AM, PM, and FM where only the first order side bands appear in the I-F signal spectrum, the linear detected signals are available at the phase detector outputs.

P-M and F-M signals are available at the output of the loop phase detector and A-M (and AGC) signals are available at the output of the amplitude phase detector. (See Fig. 9-4).

9.4 FREQUENCY LOCK

9.4.1 General

The frequency lock loop as applied to an F-M feedback discriminator for the detection of angle modulated signals is useful in three important ways:

1. To lower the detection threshold below the level obtainable using a standard F-M discriminator.
2. To maximize the detected signal-to-noise ratio by decreasing the signal margin above threshold.
3. To allow use of practical I-F amplifier bandwidths when detecting very wide band F-M signals.

The feedback discriminator varies from the standard discriminator in that the regular discriminator output through a low-pass filter drives a voltage controlled oscillator used as the receiver local oscillator. The feedback discriminator utilizes a mixer, I-F filter, frequency discriminator, and voltage controlled oscillator (VCO) in the feedback loop. The VCO is modulated with the detected waveform and its spectrum is subtracted from the wide-band input signal spectrum to produce a resultant spectrum in the I-F amplifier containing only the first order side-bands. This process can be called F-M bandwidth or deviation compression. The I-F bandwidth inside the frequency lock loop need only be wide enough to accept the highest modulating frequency first order sidebands. The noise bandwidth of the I-F amplifier can be much less than the bandwidth of the fully deviated transmitted signal as required in the I-F amplifier preceeding the standard F-M detector. Therefore, using the feedback process, the F-M threshold level of feedback detector can be much lower than the threshold level of the standard F-M detector. What the above means is that

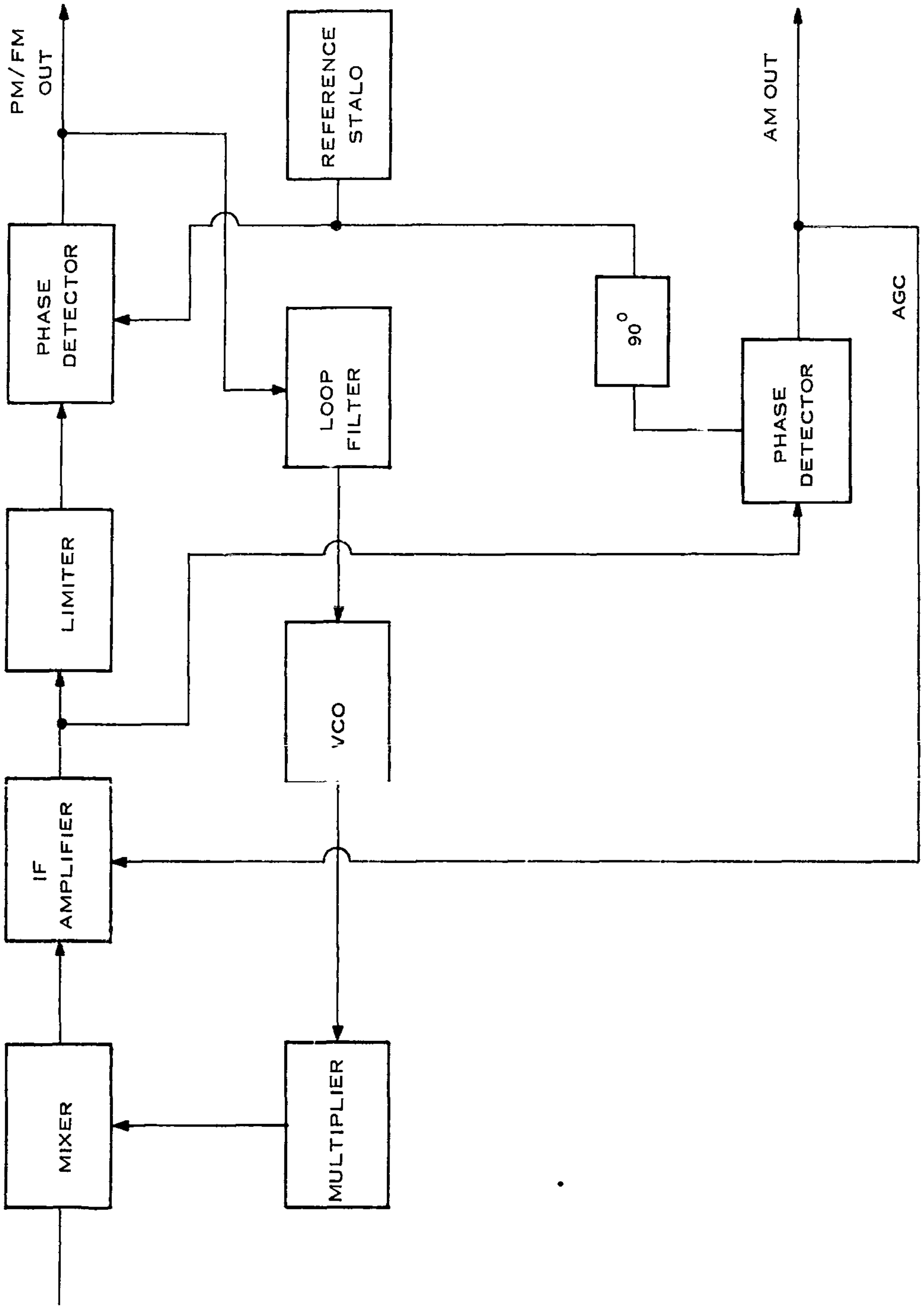


Fig. 9-4 Detection and AGC Signals from Phase-Lock Loop

when using F-M feedback, the input signal power level to the receiver can be several db lower than the condition without feedback.

There are several other considerations to be noted. They are:

a. The SNR in front of the frequency discriminator must be at least 9- to 12- db whether or not feedback is used

b. The SNR in the closed loop noise bandwidth must be above threshold

c. The conditions stated in (a) and (b) above must be met simultaneously.

It is anticipated that the maximum bandwidth of any signal can be equal to 1 per cent of carrier frequency, e.g. 20 mc at 2 Gc, or 100 mc at 10 Gc. Such a case is considered in the design of the multipurpose receiver. The amplifier bandwidths are a maximum of 30 mc and 1 mc for the first and second I-F amplifiers respectively. Feedback bandwidth compression is necessary for carrier frequencies above 3 Gc (i.e., 1 per cent of 3 Gc is 30 mc).

The transfer function of the frequency lock loop from the receiver input to the VCO output is:

$$H(S) = \frac{(F-1)\ a\ b}{S^2 + (a + b)S + abF} \qquad (9\text{-}20)$$

where: F = Feedback factor

F = 1 + Kv kd GN

Kv = VCO constant in cps/volt

Kd = Discriminator constant in volts/CPS

N = Frequency multiplier

G = Gain of video amplifier in units

a = 1/2 bandwidth of single pole IF amplifier filter in radians per second

b = Bandwidth of video filter in radians/sec.

The 3 db bandwidth of the loop (phase margin equal to 65 degrees) is:

$$Fn = B_b \sqrt{MF} \qquad (9\text{-}21)$$

where: $B_b = \frac{b}{2\pi}$ in cps

B_n = 3 db bandwidth in CPS

$M = \frac{a}{b}$

The double sided noise bandwidth of the loop is:

$$2B_L = \frac{\pi B_b}{2\rho} \sqrt{MF} \qquad (9\text{-}22)$$

where: ρ = damping factor

$2B_L$ = noise bandwidth in cps

The design of the feedback discriminator is rather complex requiring optimum settings for f_b, M, and F when Bn is set equal to the maximum modulating frequency. Further, the I-F amplifier can have only a single significant pole to insure the loop will not oscillate. F must be set optimum in accordance with the input signal frequency deviation. That is, the higher the frequency deviation, the higher the value that F must be. F is generally expressed in db and is called the feedback factor. In general then, the values of Bn, $2B_L$, B_b, M, and F will need to be adjusted and optimized for each signal to be received in order to optimize the receiver threshold. All of these of course are not independent parameters.

It is necessary to determine whether the VCO should be fed back to the first, second, or both first and second mixers. When the highest modulating frequency is less than 500 kc, double conversion can be used. For input frequency deviations less than 6 mc, the VCO could be fed to the second mixer; (based on capability of VCO). For deviations greater than 6 mc and modulating frequencies greater than 500 kc, single conversion must be used and the VCO is fed to the first mixer. It is necessary that the first mixer be used for the VCO signal insertion. Next question: Is there an advantage of feeding the VCO into the second mixer?

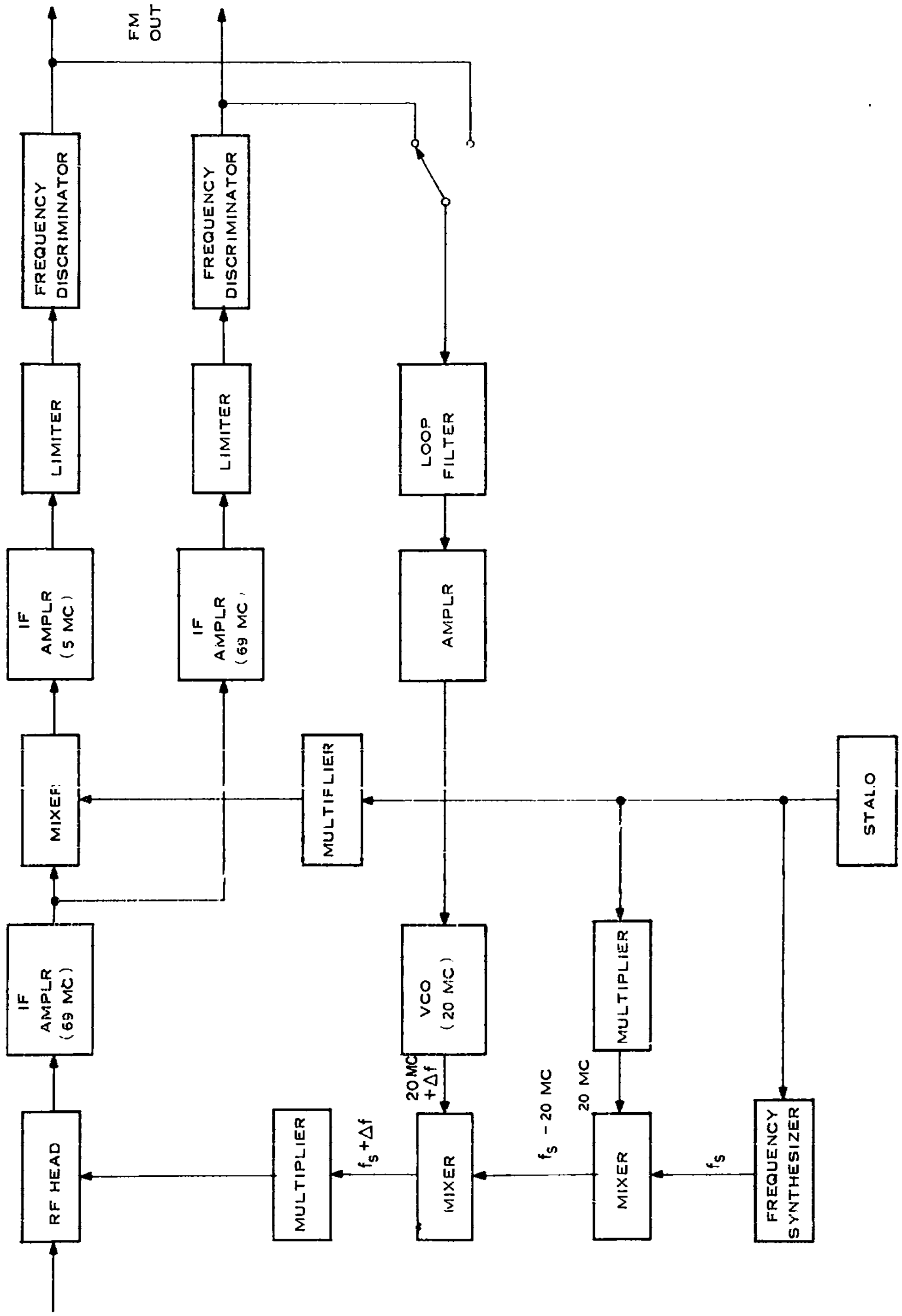
The loop closed at the second mixer will have less gain by a factor of 100 mc to 6 mc or 16.7 to 1. The gain of the system, and, therefore, incidental F-M problems are reduced when using the second mixer. A by product is that the VCO can be shared with the phase lock loop.

For the F-M feedback discriminator design, the loops will be closed at the first and second mixers.

9.4.2 VCO at First Mixer

A block diagram of the F-M feedback discriminator with the VCO inserted at the first mixer is shown in Fig. 9-5. The block diagram shows F-M outputs at each I-F amplifier, the selection of which depends on the magnitude of the highest modulating frequency.

For a modulation index of 0.7 within the I-F amplifier, leaving essentially no power in sidebands higher than the first, will leave the maximum discriminator output voltage nearly a constant. Therefore, if the deviation of the input signal changes, the VCO or video amplifier gain in feedback loop must also change if the modulation index of 0.7 is to be maintained. The open loop gain of the loop for an input signal modulation index of 20 will need to be:



Fix 9-5 Functional Diagram of FM Feedback Discriminator with VCO at First Mixer

$$Kol = \frac{20 - 0.7}{0.7} = 27.6 \text{ or } 28.8 \text{ db} \tag{9-23}$$

where $Kol = Kd\ Kv\ GN$

The feedback factor ($F = 1 + Kol$) will then need to be:

$$F = 29.1 \text{ db} \tag{9-24}$$

Thus it can be seen that F, and therefore the maximum loop gain, is a function of the input signal modulation index. For our purposes here, F will be limited to 27 db and therefore the modulation index will be limited to about 16 when the compressed index is 0.7. When the compressed index is 2 or 3, larger input modulation indices can be used.

It will be necessary for the VCO to operate at a center frequency of 20 mc with an expected gain constant of kv = 150 kc/volt. There will be three discriminators to be considered. Two at the output of the first I-F amplifier with 1-volt outputs and bandwidths of $\pm$ 5 mc and $\pm$ 10 mc. The other is at the output of the second I-F amplifier with a 1-volt output in a bandwidth of $\pm$ 500 kc. Since

$$NKv\ Kd\ G = F-1 \tag{9-25}$$

$$NKv\ Kd\ G = 21.4 \tag{9-26}$$

for $F = 27$ db

In determining the gain G of the amplifier, the value of N varies widely at the first mixer. The largest gain will be required for the 10-mc discriminator.

$$NG = \frac{21.4}{KvKd} \tag{9-27}$$

$$NG = 1.43 \times 10^3 \tag{9-28}$$

when $Kv = 1.5 \times 10^5$ cps/volt.
$Kd = 1$ volt/10^7 cps

For this case, the highest modulating frequency will fall between 5 and 10 mc. The lowest R-F frequency assuming 1 per cent bandwidth is 1 Gc when the modulation index is less than 1. For this limiting case, N = 32 and G would be 44.6.

For the case when the 5-mc discriminator is used, NG = 7.2×10^2. The maximum modulating frequency for this case will fall between 500 kc to 5 mc. For 1 per cent bandwidth, the carrier frequency could be as low as 100 mc. Therefore, N could be as low as 2 or 4. G would then vary between 360 to 180 for N equal to 2 and 4 respectively.

The amplifier bandwidth will be the 3-db single pole loop filter. Therefore the bandwidth of the amplifier will need to be as wide as 10 mc when G = 44.6 and must be as wide as 1 mc when G = 360.

The latter situation discussed above will be more than adequate for the 500-kc discriminator (Table 9-7 contains the allowable frequency deviations in each band.)

Resistor pads will also require switching when switching between R-F bands in order to keep the loop gain constant.

The problem of incidental FM must be carefully watched at the VCO and video amplifier inputs. For example, at S-band where NKv equals 9.7 mc/volt, the VCO output referenced at mixer will vary 9.7 kc for one millivolt of hum, noise, or pickup at the VCO input. D-c levels will be compensated by a bias voltage from the discriminator. Random changes or hum pickup will appear in the detected output.

It is therefore recommended that the VCO filter, amplifier, and the frequency discriminator be located close together on the <u>same</u> chassis and be well shielded with cable leads well filtered.

TABLE 9-7

ALLOWABLE FREQUENCY DEVIATIONS

Band	(Units)	Maximum Deviation (Mc)	N K v (Mc/volt)
1	256	± 51.2	38.4
2	128	± 25.6	19.4
3	64	± 12.8	9.7
4	32	± 6.2	4.85
5	16	± 3.2	2.4
6	8	± 1.6	1.2
7	4	± 0.8	0.6
8	2	± 0.4	0.3
VCO	$K_v = 150\ K_c/_v$ $\Delta f = 200\ K_c$		

For the receiver operation, suitable bandwidths and feedback factors must be selectable. The video amplifiers for the output signal will have bandwidths selectable from 0.03, 0.1, 0.3, 1, 3, and 10 mc. The feedback factor will vary from 3 to 27 db in 3-db steps.

9.4.3 VCO at Second Mixer

A block diagram of the F-M feedback discriminator with the VCO inserted at the second mixer is shown in Fig. 9-6.

The design at the second mixer will have a single VCO gain for the 69 mc IF another fixed gain for the 21 mc IF. The deviation of the VCO can be 2 per cent and still have a linerity of better than 1 per cent, i.e., the change in slope will be less than 1 per cent. The frequency deviation will be approximately ± 7 mc for the 69 mc IF and ± 2 mc for the 21 mc IF. There will be a single frequency discriminator used here with a gain constant of 1 volt per 500 kc.

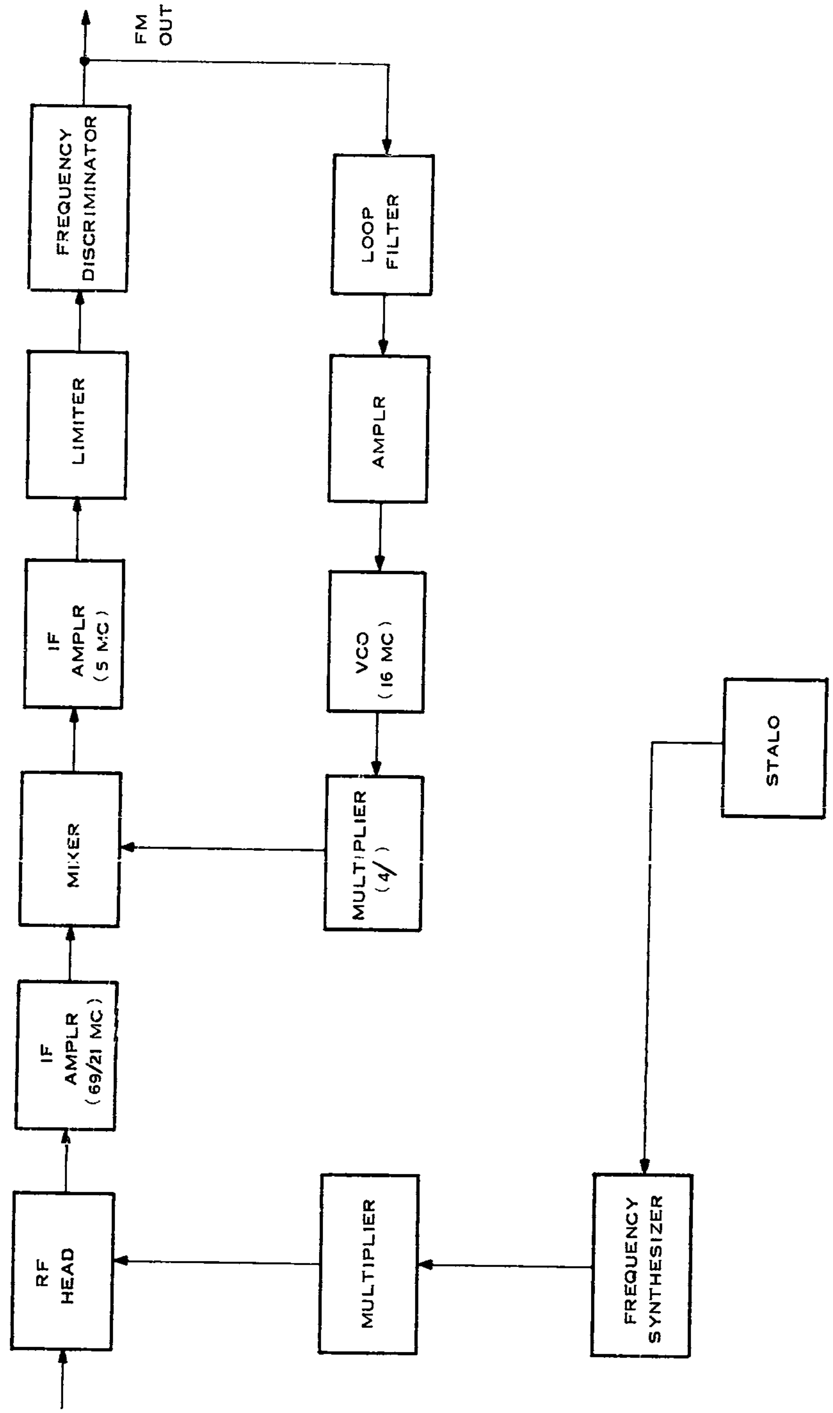


Fig. 9-6 Functional Diagram of Feedback FM Discriminator with VCO at Second Mixer

For 27 db feedback, the amplifier gain G will be:

$$G = \frac{F-1}{NKvKd} \tag{9-29}$$

$$G = 21.4 \tag{9-30}$$

where F = 27 db
N = 4
Kv = 125 kc/volt
Kd = 1 volt/500 kc
Fo = 16 mc

For the 21 Mc IF, the gain will need to be 85.6 for 27 db feedback. The loop amplifier gain should then be variable up to a 100. As before, the loop filter should be the 3db cutoff of the amplifier.

9.4.4 Example of Threshold Improvement

An example will be shown that illustrates the threshold improvement that can be obtained with a specific index of modulation. With large indexes of modulation threshold improvements as high as 10 db can be obtained. There will be no attempt in this report to derive the formulas used.

Consider the following problem:

B_{NRF} = 880 kc (R-F bandwidth)

ΔF = $\pm$ 360 kc (Deviation)

β_{RF} = 9 (Modulation Index)

f_m = 40 kc (Modulating Frequency)

The threshold using a standard discriminator for these parameters is approximately 10 db. Calculate the threshold reduction using feedback

The required feedback factor F is determined:

$$F = \frac{\beta_{RF}}{\beta_{IF}} \tag{9-31}$$

$$F = 9 \tag{9-32}$$

when $\beta_{RF} = 9$

$\beta_{IF} = 1$

$\beta_{IF} = 126$ KC.

The SNR at threshold in the closed loop noise bandwidth is:

$$\rho_t \approx 4.8 \left[\frac{F-1}{F}\right]^2 \tag{9-33}$$

$$\rho_t = 3.8 \text{ or } 5.8 \text{ db.} \tag{9-34}$$

The value of N (the ratio of $\frac{\beta_{IF}}{2}$ to video bandwidth within feedback loop) is:

$$N = 1 \tag{9-35}$$

The value of the damping factor is:

$$\zeta = \frac{N+1}{2\sqrt{NF}} \tag{9-36}$$

$$\zeta = 0.33 \tag{9-37}$$

The bandwidth B_b of the low pass filter is:

$$B_b = 140[illegible] \text{ Kc} \tag{9-38}$$

The value of B_n (loop natural frequency) is:

$$B_n = B_b \sqrt{NF} \tag{9-39}$$

$$B_n = 120 \text{ Kc} \tag{9-40}$$

The double sided loop noise bandwidth is:

$$2B_L = \frac{\pi \, Bn}{2 \, \zeta} \tag{9-41}$$

$$2B_L = 565 \text{ kc} \tag{9-42}$$

Assuming the R-F bandwidth of the receiver when not using feedback is 880 kc, the ratio of the noise R-F to the closed-loop noise bandwidth is 1.56 or 1.9 db.

The SNR in the IF bandwidth must be above the discriminator threshold ρ_{oL} or at least + 9 db.

The situation is confirmed as follows:

$$\rho_{oL} = 10 \log_{10} \left[\rho_T \frac{B_L}{B_{IF \text{ noise}}} \right] \tag{9-43}$$

$$\rho_{oL} = 12.3 \text{ db} \tag{9-44}$$

when B_{NIF} noise = 126 Kc.

The total threshold improvement of the feedback discriminator over the standard discriminator is:

$$\text{Threshold Improvement} = 10 \text{ db} + 1.9 \text{ db} - 5.8 \text{ db} \tag{9-45}$$

$$\text{Threshold Improvement} = 6.1 \text{ db} \tag{9-46}$$

9.5 AN ALTERNATE FRONT-END DESIGN

The proposed front-end design of this multipurpose receiver has several advantages. The first of these is that the design hardware is minimized. Secondly, the gain and bandwidth of the frequency and phase-lock loop can be increased easily as the frequency increases. Thirdly, the radio interference problems are reduced.

However, there are arguments which suggest that it may be more desirable to include an additional mixer and IF at approximately 840 mc. The inclusion of the additional mixer combination would relieve the multiplier chain feeding the first mixer of the modulation process. For instance, if an F-M signal is applied to the chain having a bandwidth of 10 per cent, it is conceivable that the center frequency may lie close to the edge of the multiplier chain. The result is serious distortion of the modulating signal. Of course, the bandwidth could be extended to provide over-lap, but as pointed out in the r-f discussion, the attainment of 10 per cent bandwidth in multi-coupled multipliers is a fairly difficult engineering problem at this date. Another alternative then would be to retune the multiplier chain so that the signal is at nominal center of the multiplier chain. This problem can be avoided by using the intermediate mixer-IF scheme.

Reference to Figure 9-7 will aid in the understanding of the system under discussion. The first mixer functions to convert all signals to one of the three frequencies: 840 mc, 69 mc and 21 mc. For operation up to 1 Gc, the 69- and 21-mc conversions are employed. Above 1 Gc, the 840 mc is required. The 840 mc is amplified and converted to 69 mc. (The VCO operating frequencies would have to be changed from 20 mc to 16 mc.)

A disadvantage of this approach for phase lock is that the frequency deviation (for $2B_L = 1$ cps) is fixed at $\pm$ 4.8 kc. The synthesizer (tuning) resolution would be increased to 1×10^{-7} to operate at 10 Gc.

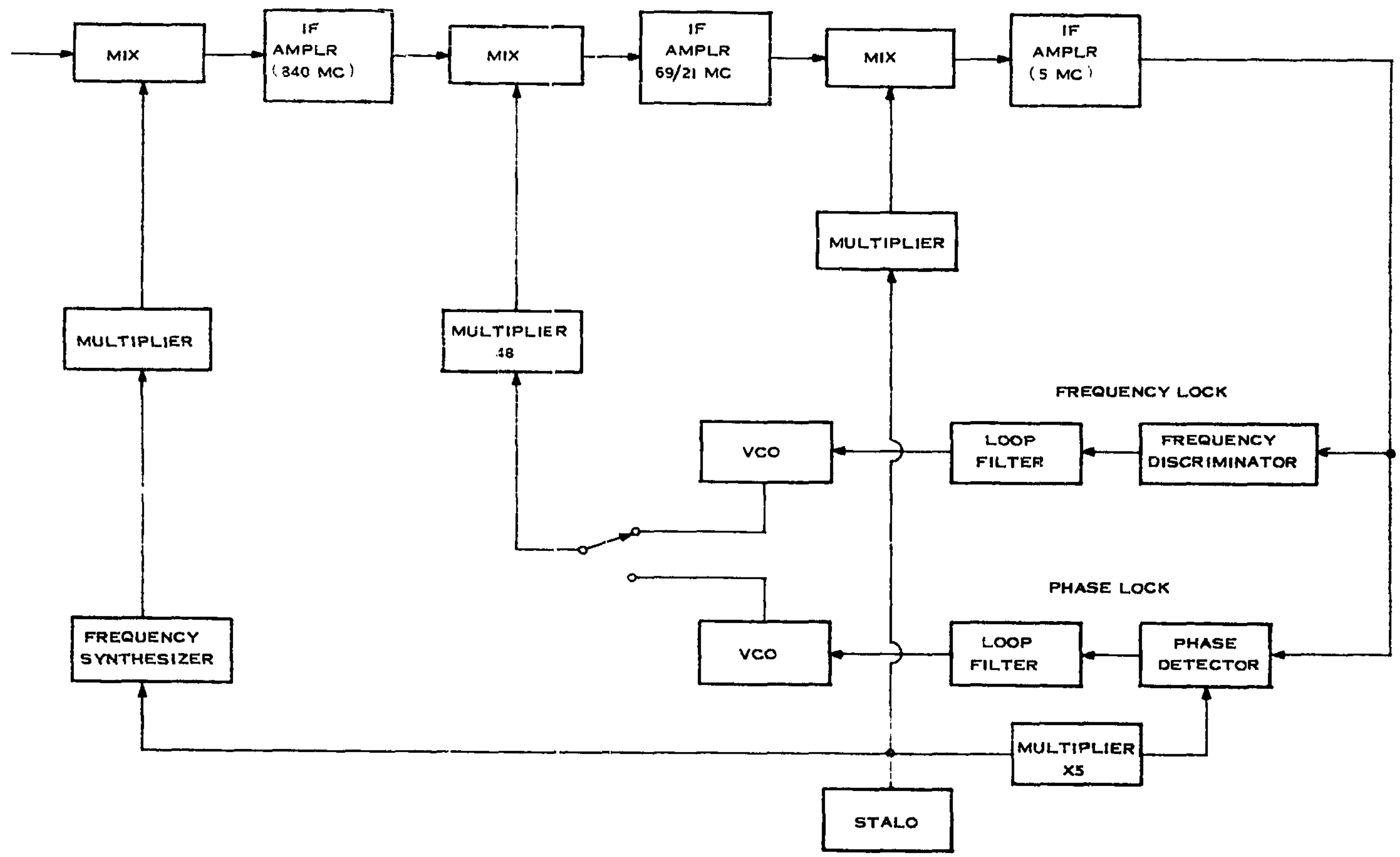


Fig. 9-7 Alternate System for Phase and Frequency Lock

Another problem posed by this system is in the 840 mc amplifier. This amplifier must meet the following specifications:

a. All solid-state construction
b. Noise Figure - 2 db Max.
c. Gain - 20 db
d. Bandwidth - 100 mc
e. Center Frequency - 840 mc

As of this date, it appears that a tunnel diode type amplifier may be available. If this situation materializes, this scheme has the following two advantages.

1. Only one frequency-or phase-lock loop will need to be designed for use with signals in the 1 Gc and above range. An optimized design can be achieved since all gains and conditions are similar for these frequencies.
2. The r-f multiplication specifications can be eased since a flat response and/or a wider bandwidth need not be so stringent.

The operation then of the revised receiver front end system would be as follows: For operation below 1 Gc, the 21-mc IF and 69-IF are used in the normal manner. When the receiver is switched to receive 1 Gc and higher signals, the 840-mc section and the extra multiplier strip to extend the VCO is also automatically switched on. The 840-mc signal is converted to 69 mc and processed in normal operation.

9.5.1 Mechanical Considerations

The mixer, 340-mc amplifier, intermediate mixer and additional multiplier stage would be mounted in the r-f section of the receiver. The local oscillator for conversion of the 69 mc to 5 mc would be obtained from the synthesizer section. The largest mechanical items will be the switches. Total volume for the mentioned units is estimated to be 84 cubic inches and consists of 7 modules, each of which is approximately 2 inches by 2 inches by 3 inches.

In summary, it appears that this system has much to offer; an optimized phase or frequency lock system for all frequencies above 1 Gc and a somewhat simpler requirement on the frequency multiplier chain. The price paid for these improvements is a modest increase in the VCO frequency multiplier, a low-noise high frequency amplifier, a local oscillator source for the 69-mc mixer, and an increased synthesizer resolution.

9.6 AUTOMATIC FREQUENCY CONTROL (AFC)

An AFC system during F-M reception will be necessary to keep the input signal in the center of the I-F passband when the signal frequency varies due to transmitter frequency instabilities and doppler frequency shift.

The AFC will be needed when receiving F-M signals when frequency lock is not employed. The AFC will use the same VCO's as is used in frequency lock.

The main additions to the receiver due to AFC over that needed for frequency lock is the loop filter.

The design details will not be considered in this report, but they will depend largely on the tracking and search ranges and the desired transient response.

9.7 ACQUISITION CONSIDERATIONS FOR PHASE LOCK

The block diagram for the required automatic acquisition circuits is shown in Fig. 9-8.

The problem of signal acquisition occurs when the VCO frequency differs from the input signal frequency by an amount larger than the pull-in frequency range of the phase lock loop.

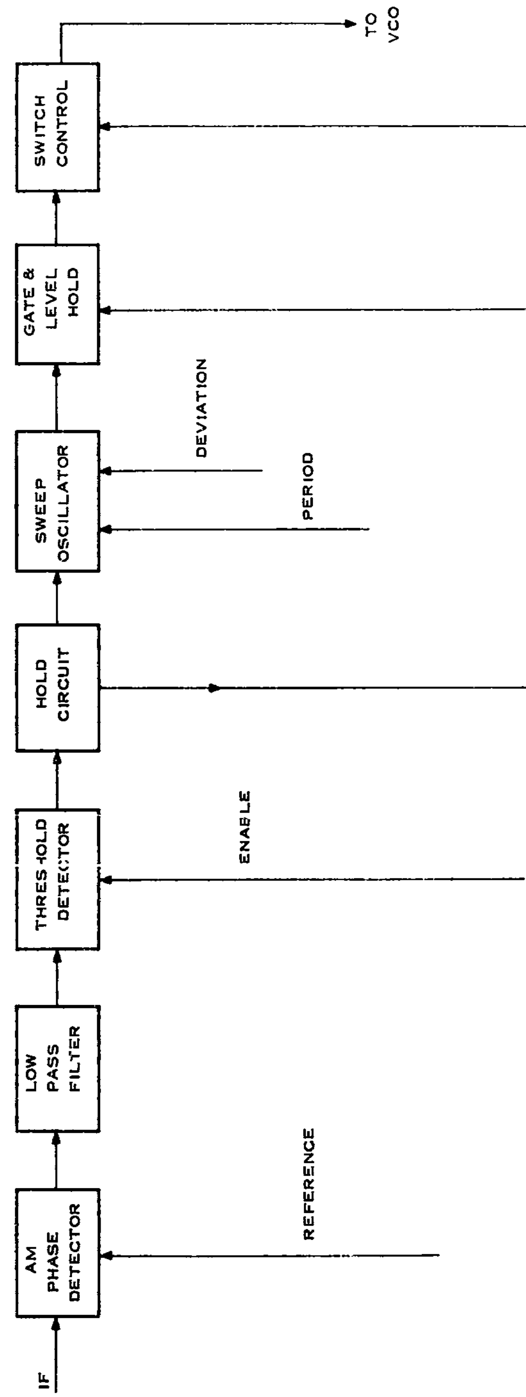


Fig. 9-8 Functional Block Diagram of Phase-Lock Acquisition Sweep System

Two methods are normally used to tune the VCO frequency to equal the signal frequency. Those are manual and automatic. For manual acquisition, the automatic acquisition circuits of Fig. 9-8 are not used. All that is necessary, is for the VCO frequency to be varied or tuned manually.

In the automatic acquisition mode, a sweep of predetermined period and deviation sweeps the VCO frequency about the expected value of the input signal frequency. As the two signals approach the same frequency and phase, they are cross-correlated in the A-M phase detector followed by a low pass filter. A d-c voltage (ramp of voltage) appears at the filter output and when the magnitude of the voltage reaches a predetermined threshold value, the sweep oscillator is turned off, stopping the automatic sweep to the VCO. If the VCO frequency is within the pull-in range of the loop and the loop SNR is above threshold, the loop will pull-in to phase lock.

After the sweep is terminated it is important that the sweep be held terminated by a hold circuit to prevent the sweep from restarting from noise pulses and other effects. It is important that the sweep source voltage applied to the VCO be held constant when the sweep is terminated to prevent the VCO from changing or drifting in frequency. Finally a switch circuit (relay or electronic switch) should remove the load impedance and the sweep circuit voltage from the VCO.

The sweep must be prevented from starting without a manual "enable" during fades or temporary loss of input signal.

The maximum allowable sweep rate will be:

$$D = 0.18\, B_{nf}^{2} \tag{9-49}$$

where D = sweep rate in cps

B_{nf} = two sided noise bandwidth of correlation detector filter.

The SNR within B_{nf} is set to a value dependent upon the false alarm rate allowed and the threshold level for the threshold detector is set accordingly. If, for example, the SNR desired is + 12 db, the IF SNR would then be + 12 db + 10 $\log_{10} \frac{B_{nf}}{B_{IF}}$. The IF SNR will therefore set a limit on the maximum sweep rate when a correlation SNR is assigned.

An important consideration is to be pointed out: The noise from the IF amplifier in the absence of signal (and therefore AGC) will be a constant value in a fixed B_{nf}. If B_{nf} is to be increased to decrease the acquisition time, the threshold level will need to be increased due to the increased noise.

To increase B_{nf}, one must expect a larger receiver input signal power level. For larger input levels, one can use a larger phase-lock bandwidth. It is therefore sensible to switch the AGC voltage level (without signal) when switching phase-lock noise bandwidths for fixed B_{nf}, and for a fixed phase-lock bandwidth, the threshold level should be increased for an increased B_{nf}.

9.8 AUTOMATIC GAIN CONTROL (AGC)

9.8.1 Need for AGC

Automatic Gain Control (AGC) is needed to keep the predetection amplitude modulated signal constant and the monopulse error channel I-F gain changes identical to the reference channel so that their detection processes will produce the desired output signal. Limiters are used in angle modulation detection and in both frequency and phase lock detectors. AGC is needed here to keep the limiter drive power below a prescribed limit.

The specifications for this receiver state that the AGC must keep the output levels within 3 db of a nominal prescribed value, and that selectable noise bandwidths need to be included.

9.8.2 AGC Design

The AGC designs using conventional uncorrelated detection (envelope detector) and phase lock correlated detection are similar. Over a 3-db dynamic range of the input signal the closed loop transfer function will be approximately:

$$H(S) = \frac{1}{1 + \frac{\tau}{G} S}$$

where τ = filter time constant
G = loop gain

The 3 db loop bandwidth is:

$$BW_{3\ db} = \frac{1\pi\ G}{2\tau} (cps)$$

and the double sided noise bandwidth is:

$$BW_{noise} = \frac{1}{2} \quad \frac{G}{\tau} \ (cps)$$

The gain of the loop G is composed of two components K_A and K_D so that $G = K_A K_D$. Where K_A is the gain constant of the I-F attenuator in db/volt and K_D is the amplifier gain constant in volts/db. The AGC amplifier must have a sufficiently wide bandwidth so that phase shift from its poles do not significantly reduce the phase margin at the AGC servo. It must be noted that the low pass filter 3-db bandwidth or corner frequency is not equal to the closed loop 3 db or noise bandwidths.

When using correlated and uncorrelated AGC, the values of K_D in general will be different and if K_A is common, one of the K_D's will need to be modified to prevent switching the time constants for specific noise bandwidths when switching between the two types of AGC. The time constants are normally switched when changing AGC bandwidths.

Since the amplified characteristics and the I-F attentuators will not in general be straight line functions, the shape or gamma of the AGC characteristics must be adjustable. Likewise the threshold or delay will require adjustment for various operating situations.

For monopulse operation, the AGC must have sufficient output and independent controls to be used with three I-F amplifiers. Such is the case for this receiver.

The AGC loop bandwidth is chosen for a desired transient response.

9.8.3 Design Example

The maximum dynamic range of the receiver for double conversion is 124 db. If a voltage controlled attenuator is used having a gain constant K_A = 10 db/volt, then the total voltage change will be 12.4 volts.

The phase detector gain constant is 0.035 volts per degree and the peak output voltage will be 2.1 volts. A 3-db change would be 0.87 volts. The gain of the AGC amplifier is therefore approximately 15 and the amplifier gain constant will be K_D = 5 volts/db. The value of $G = K_D K_A = 50$.

Selecting the noise bandwidth ($2B_L$) of the closed loop, the 3-db bandwidth, filter time constant and bandwidth are calculated. Several values are shown in Table 9-8.

TABLE 9-8

AGC DESIGN

$2B_L$ (cps)	$B_{3\ db}$ (cps)	τ (seconds)	Filter Band-width (cps)
0.3	0.096	79	2×10^{-3}
1	0.318	25	6.4×10^{-3}
3	0.96	7.9	2×10^{-2}
10	3.18	25	6.4×10^{-2}
30	9.6	0.79	2×10^{-1}
100	31.8	0.25	6.4×10^{-1}

9.9 DETECTION OF P-M, F-M, AND A-M SIGNALS

For A-M, P-M, and F-M where only the first order sidebands appear in the I-F signal spectrum, the linear detected signals are available at the phase detector outputs. P-M and F-M signals are available at the output of the loop phase detector and A-M (and AGC) signals are available at the output of the amplitude phase detector. (See Fig. 9-4).

9.10 DETECTION OF OTHER TYPES OF SIGNALS

The versatility of this receiver permits easy adaption to reception of various modulation schemes. Because of the modular plug-in design, it becomes convenient to utilize the receiver as newer modulation systems are introduced. For example, although the receiver was not designed specifically for direct carrier bi-phase modulation ($\pm 90^{o}$), it is fairly simple to accommodate the hardware needed to detect this modulation. Several additional modules would be required. One module would house the VCO, its times two multiplier and phase detector, and second module to house a second phase detector which multiplies the VCO signal and received signal. A third module will be required to accommodate differentially coherent bi-phase modulation.

In a similar manner, DSB-SC can be received by replacing a module or two. The flexibility of the receiver is increased and obsolescence minimized.

Other types of modulation could be received by designing and incorporating additional modules.

SECTION 10

REMOTE CONTROL OPERATION

10.1 THE NEED FOR RECEIVER AUTOMATIC CONTROL

The satellite systems now in operation require a complex array of functional components to locate, track and communicate with a space vehicle. New systems and improvement of existing systems will further increase the complexity of future systems. Because of this increase in complexity, it is necessary to include a greater amount of automation in system control to reduce the burden of decision required of the operator during a mission. Automation of the control system can also increase the system operating speed. In a typical mission only a very short time is available for the reception of data. Many tracking systems now set to the approximate azimuth bearing of the space vehicle shortly before its approximate time of appearance on the horizon, use a sector scan technique for acquisition. If the operator must monitor the equipment for an extended period of time, fatigue reduces the likelihood of the operator observing the target on its first appearance. The scan may be in an unfavorable area increasing the acquisition time. If full advantage is to be gained from the ability to compute more precisely the exact time and position of the space vehicle as well as to use advantageously the increasingly better frequency stability of the vehicular equipment, then automatic acquisition and tracking must be used. An automatic system can maximize the amount of data that can be transmitted during the time that the telemetry signals are above threshold performance levels by using a computer to predict orbit, time of arrival, etc., and to control the receiver directly. If the full capabilities of the tracking station are to be utilized, the station and the receiver must have the capability of fast change over in frequency, signal level, bandwidth operating mode and other parameters that vary with mission. A computer can assure rapid transition from one mission to another and can also rapidly check the receiver controls for proper setting without requiring operator decision.

Computers will be used on new systems and in improved versions of existing receivers in all major systems in the immediate future. To facilitate computer operation, the multipurpose receiver will be designed for full automatic control either by a computer or other control devices.

10.2 THE NEED FOR RECEIVER REMOTE CONTROL

The receiver should be capable of full remote control. This feature is necessary because:

- The operator at the equipment can be eliminated
- If computer control is used the computer need not be near the receiver
- Automatic control of the receiver can be accomplished from a distance up to several thousand miles.

The addition of the remote control feature increases the complexity of the receiver and can be a disadvantage. Remote control of the receiver, however, will allow recording and computing functions to be located at convenient locations away from the receiver. An example is to locate a computing center in one part of the world and control a receiver via radio teletype punched tape. A week or more of receiver programming can be sent to the remote site in a few minutes. The tape punched at the receiver is immediately transmitted back to the computing center for verification. The great economic saving in a system of this type results from using one facility to control many sites.

Another advantage of remote control is the ability to disperse several antenna systems and associated receivers several miles around a hard central control site. The large dish antennas cannot be made hard, so dispersion offers a possibility of operation after a nuclear attack. Again, this type of system is reasonably economic since most of the system complexity is shared with several antenna (and receiver) systems remotely located around its perimeter.

10.3 PHILOSOPHY OF REMOTE CONTROL OPERATION

The required remote control operation can only be determined after a study of the overall mission and tracking station requirements is completed. The following is a discussion of the remote control problem based on a limited study.

10.3.1 Receiver Controller

The receiver should be controllable by two methods (in addition to back-up manual control):

a. From a central control console using a minimum of controls. The console operator would have controls of an overall nature, and would not have any of the actual receiver operating controls remoted to the console Operator controls would be limited mainly to:

(1) Program Number
(2) Space Vehicle Number
(3) Function
(4) Subroutine

b. From a station digital computer that is programmed daily or weekly to handle the necessary space vehicles. For this type of operation, the control console would obtain program status information based on the computer control.

10.3.2 Controller Concept

The controlled function of the receiver will have its control wires connected to a programmable junction box near the receiver.

a. For control console operations, control voltages would select the proper program. The device used (magnetic or paper tape, IBM card, etc.), having been selected by program, would then cause the receiver control functions to be set to

their proper positions or values. A status signal coming after the controls are positioned whould then be sent to the control console.

b. For computer operation, the computer should be capable of selecting the proper programmed device as in (a) or directly controlling some devices in the receiver. A device to be controlled directly might be the VCO tuning.

10.3.3 Receiver Program

The program must be capable of being changed as required to allow for maximum flexibility, depending upon the number and types of space vehicles that must be served.

10.3.4 Operators

Operators will play a lesser role than they do presently without the remote operation. Their chief function will be one of changing the programs and monitoring the operation. There will be no need for fast operator decision making between satellites to set up controls except on an emergency basis.

10.4 THE RECEIVER REMOTE CONTROL SYSTEM

The recommended receiver remote control system utilizes two types of servos:

a. Synchronized magnet stepping motors which accurately translate electrical pulses to incremental shaft angle position

b. A closed loop synchro, amplifier motor feedback servo for continuous shaft angle position.

The choice of the elements and of the types of controls for the multipurpose receiver were selected to meet the following requirements:

- High reliability
- Small size
- Low cost
- Low complexity
- Provide both discrete and continuous control adjustment

The ledex "digimotor" was chosen as the primary element to provide discrete shaft positioning. This unit has a distinct advantage over other stepping motors in that its output shaft can be manually turned in either direction providing manual over-ride and manual setting. Further this unit offers small size, high reliability and low cost. Since it is a pulsed device, it only dissipates heat when it is in use.

The synchro servo was chosen to provide continuous shaft adjustment because the reliability of the elements of this type servo are high, the components are small and they are reasonably economic.

Relay logic based on the radix ten is used because it is simple, low in cost, and has fair reliability. The disadvantage of this system is that it does not adapt readily to binary.

10.4.1 Examples of Remote Control Methods

Figure 10-1 is a diagram of the local portion of the remote control system for setting the frequency synthesizer and Figure 10-2 is a diagram of the remote portion of the control system for setting the synthesizer. The procedure for remote setting of the synthesizer is to depress the zero set button forcing the synthesizer decades to zero position. The correct synthesizer number is then set on the decade switches and the set synthesizer button is depressed. A stepping switch starts a scan of the synthesizer decade switches, column by column, forcing each decade stepper to the number entered in the decade switch being scanned; when all seven decades have been set, the scan is terminated.

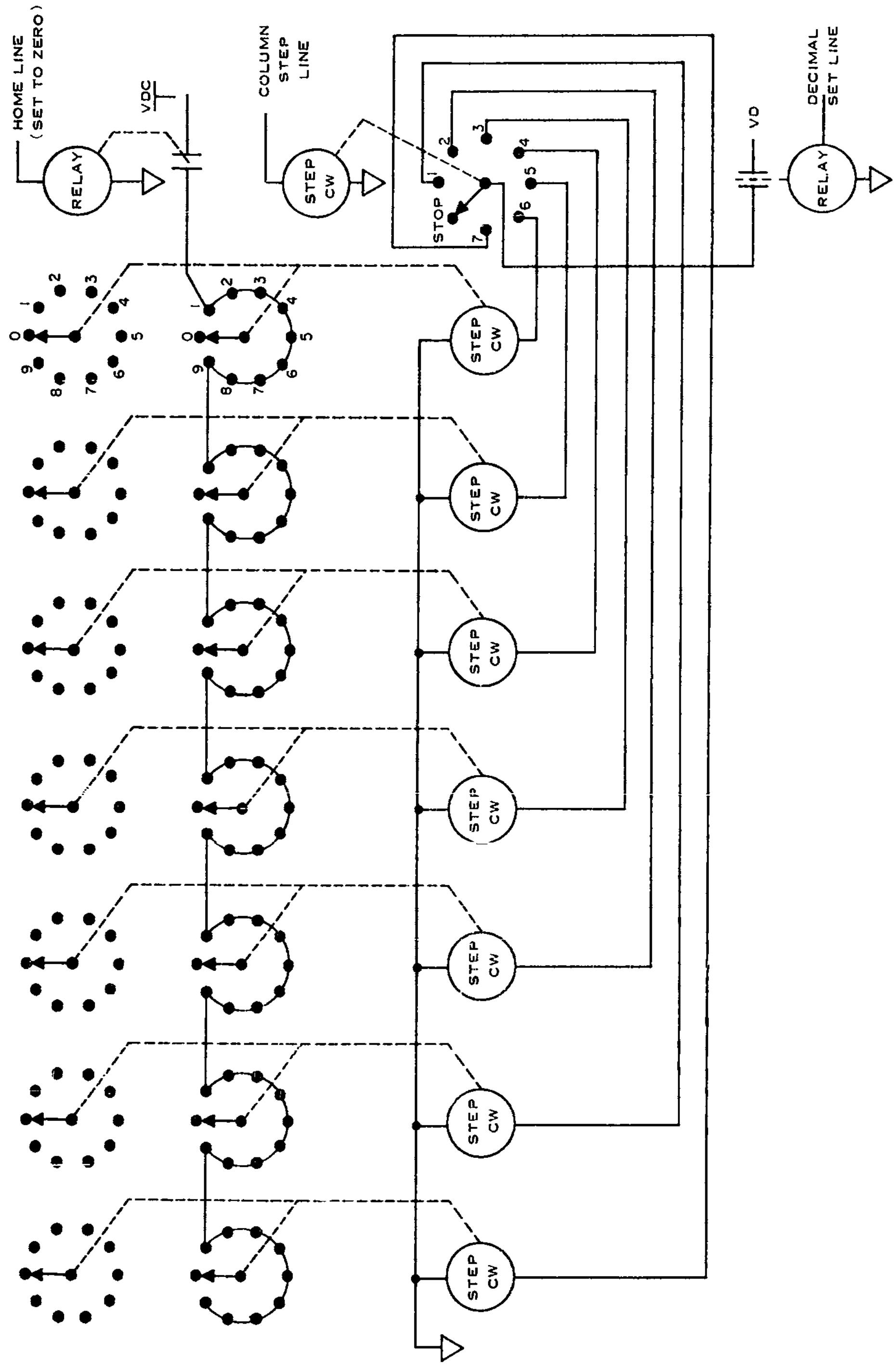


Fig. 10-1 Synthesizer Local Portion of Remote Control System

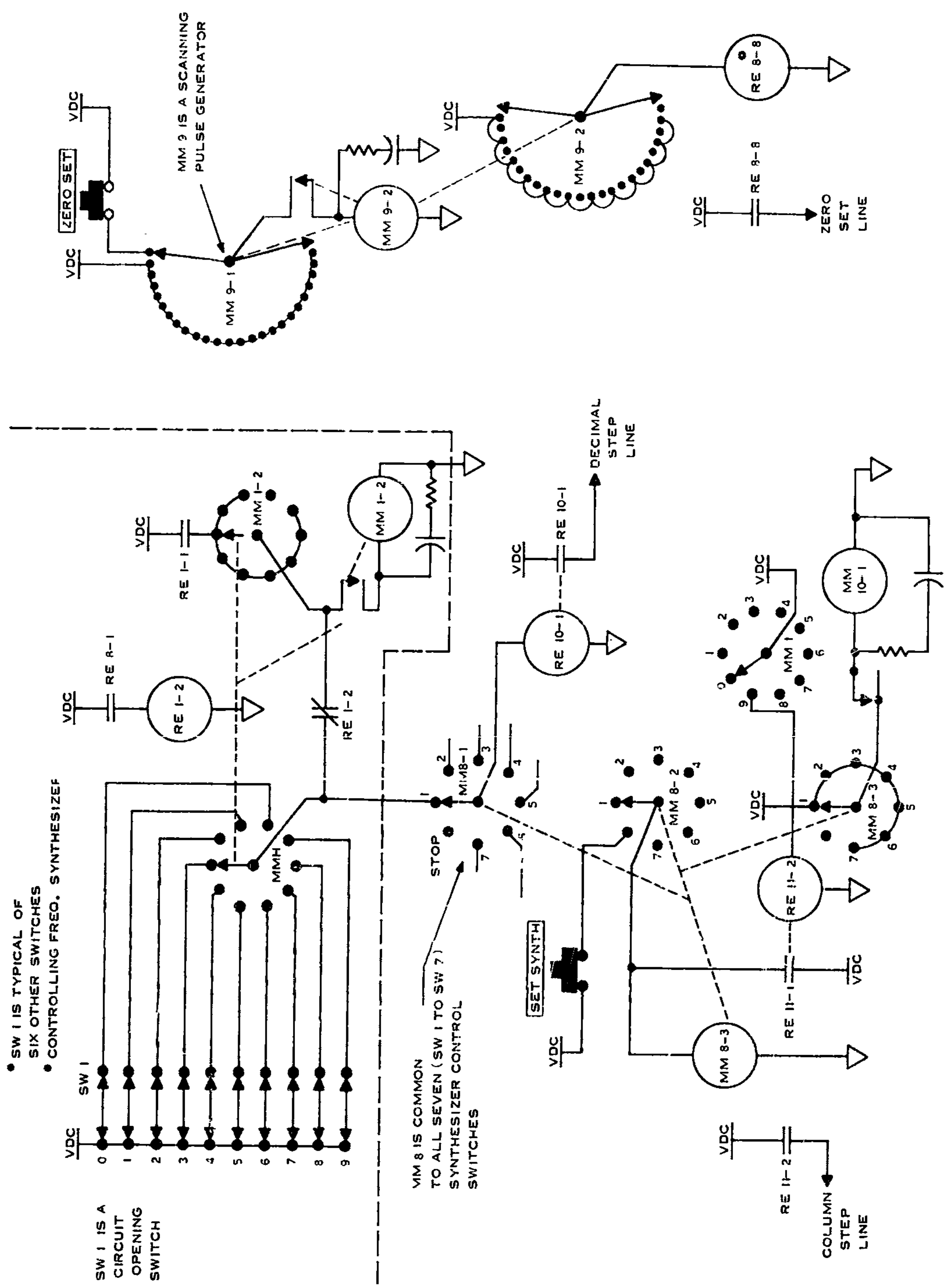


Fig. 10-2 Remote Control Portion of Frequency Synthesizer

By using this type of control only three wires and a shared common wire control the synthesizer. A similar scan system sets the sweep and the main receiver control switches. (See Fig. 10-3).

The continuous controls (VCO, Gain, etc.), are set remotely by the servo system shown in Fig. 10-4 for shaft rotations up to 360° or by the servo system shown in Fig. 10-5 for rotations larger than 360° (ten turn potentiometers). The two servos differ only in the addition of two synchros and two gear trains to resolve the rotational ambiguity of rotations greater than the 360°.

The remaining switches are remoted by wire from switch contacts and wires from separate relays.

10.5 PATCH PANEL, TAPE AND COMPUTER CONTROL AND AUTOMATIC PROGRAMMING OF THE RECEIVER

Although the exact means of automatic programming the multipurpose receiver is not a part of this report, it is interesting to examine the general problem of automatic programming and control. Since programming can be very complex several program boards can be pre-wired for each major program. Switch-over of the receiver is accomplished by inserting the proper program board and by depressing an enable switch. If the program board is regarded as a matrix with each horizontal row as an instruction word, the board can be scanned row by row into a shift register. A counter is advanced as each command word enters the register. Execution of the command starts the scan of the next row (next command) into the register. The counter arms the correct gates so that the proper receiver controls are set. If the operator chooses not to use program boards, he can select the tape mode where a punch paper tape is read block by block into the shift register (each data block corresponding to a command word) and a count again arms the correct gate in the proper sequence. The advantage of the paper tape is that it may be punched by radio teletype writer and transmitted by radio to locations in any part of the world (perhaps from a computer center). Also the equipment for punching and reading tape can be economically included as a part of most installations. A computer can be allowed to control the receiver by operator selection of the "computer control" mode.

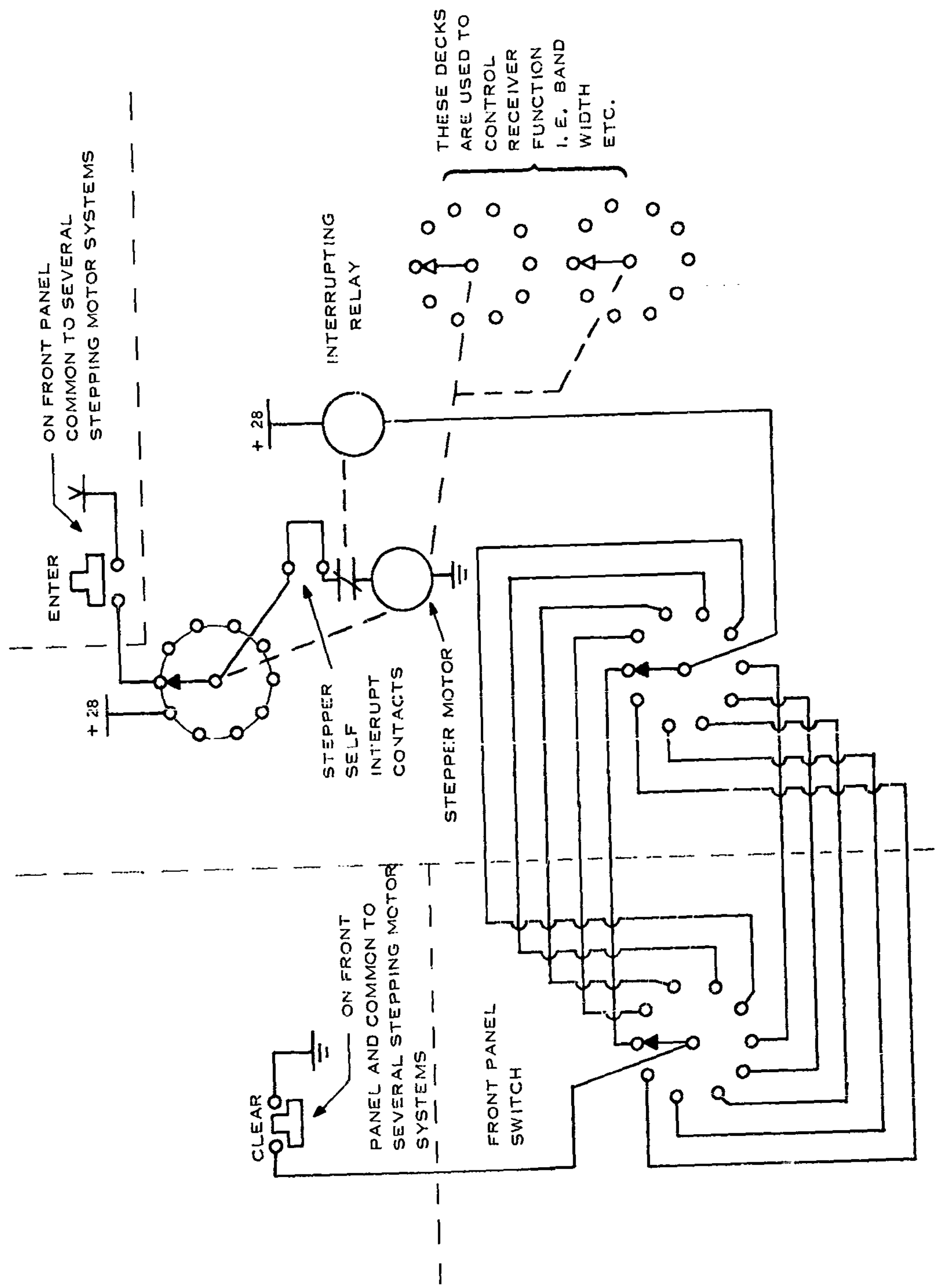


Fig. 10-3 System for Remote Setting and Clearing of Receiver Multiple Switches

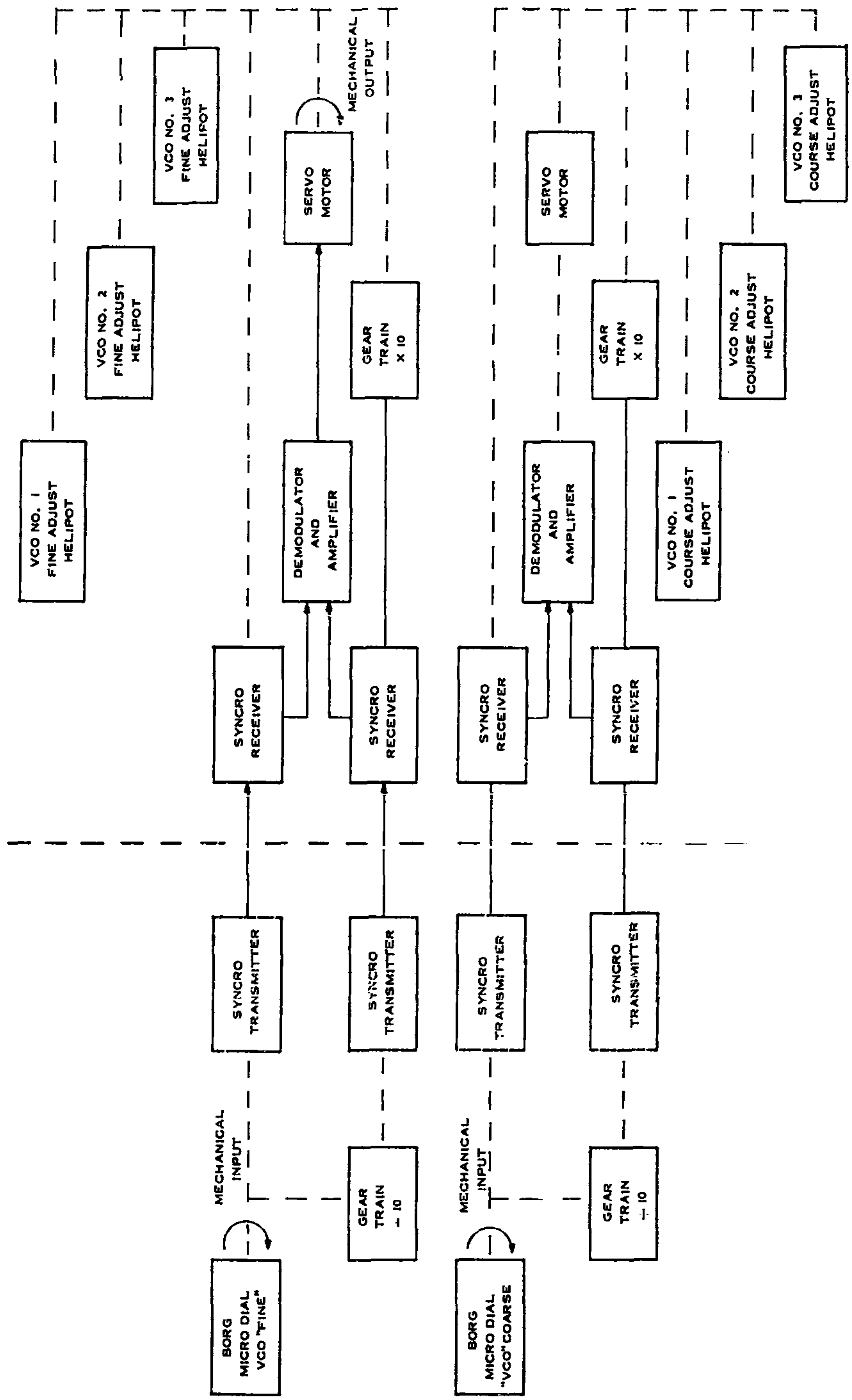


Fig. 10-4 Control Servo Remote Control System

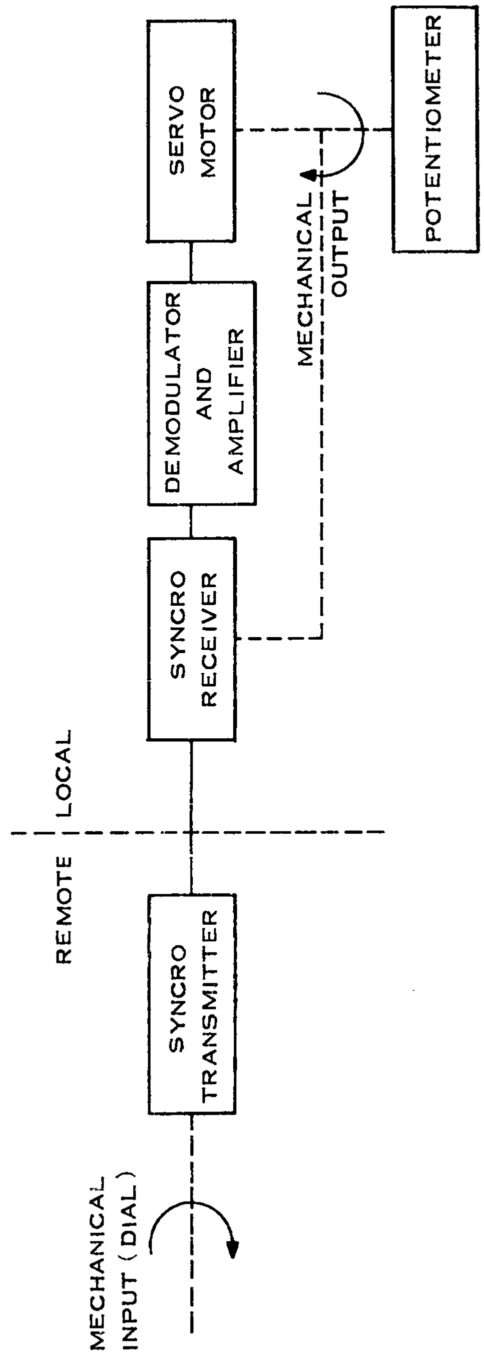


Fig. 10-5 Potenticmeter Control Servo, Remote Control for Receiver's continucusly variable Controls

To sumarize, the receiver can be automatically programmed and controlled by program patch boards, paper tape and digital computer by the addition of a black box of reasonable size, cost and complexity. The advantages of this type of programming is that it uses a prior knowledge to increase the receiver utility and to reduce the complexity (from the operators viewpoint) and the time required to change the receiver to a different set of operating conditions.

SECTION 11
FAILURE REPORTING AND ISOLATION SYSTEM

11.1 INTRODUCTION

The reliable performance of the receiver is contingent upon several conditions. The first condition requires that a sound engineering circuit be developed and adequately tested. For example, a circuit may be required to perform several tasks when actually the tasks should be performed by a more complex circuit. Although more components are required, the proper circuit performance would be secured. The second requirement is that the high-quality, properly rated component be carefully selected. The third requirement revolves about careful maintenance and operation of the receiver. Repairing a defective unit only to neglect correct alignment seriously reduces the reliability of the receiver. Periodic tests to evaluate the receiver operation and performance can do much to reduce the down-time and operating costs.

This section of the report is devoted to the various methods of failure-detection and fault-isolation which are needed because of the unavailability of a sufficient number of qualified personnel to maintain the receiver at the high operational level needed for these space programs.

11.2 REQUIREMENTS

The Failure Reporting and Isolation System (FRIS) is one that provides the following:

1. Monitors all modules either continuously or periodically

2. Indicates an approaching failure condition by monitoring the limits of operation for a component, module, or circuit function

3. Indicates the failed module or modules and initiates an alarm

4. Determines whether the receiver is in operating condition or is giving marginal performance

5. Functions during receiver operation

6. Exercises the receiver through its functions in a dynamic testing procedure

7. Self-checks for its own failures

8. Provides reliable performance

9. Is low in cost

10. Can be operated remotely or by a computer.

11.3 METHODS OF TESTS

The requirements of Paragraph 11.2 involves static, dynamic, and operational test methods.

11.3.1 Static Testing

Static testing involves monitoring certain module test points for voltages or current, ac or dc. The assumption is made that changes of these static values will indicate a malfunction. This method is extremely attractive for catastrophic module failure, is the least expensive, and provides the simplest type of information. Applied carefully, static testing can yield a great deal of information.

11.3.2 Dynamic Testing

Dynamic testing reveals the operational performance that the static testing may possibly ignore. The receiver is subjected to a simulated receiver signal and is tested for response to this test signal. For testing the multipurpose receiver the test signals must have the following characteristics:

a. Precisely controlled with respect to stability and amplitude
b. Varied to prescribed tracking rates
c. Deviable to wide excursion, and up to high modulating signals
d. Various types of modulation.

Examination reveals that Extensive testing of the receiver's characteristics will be required.

11.3.3 Operational Tests

Receiver performance can be evaluated very easily using the actual signals, providing previous experience has been gained with the source.

11.4 FAILURE REPORTS

There are three basic levels of failure reporting: manual, semi-automatic, and completely automatic. In addition, any combination of signal types can be applied to any one of the above levels.

11.4.1 Manual Operation

Manual operation is characterized by all operator operation. Test points are provided at each module; but operator skill is required to recognize a malfunction, to trace the malfunction to its cause, and to rectify the failure. Accordingly, this manual check-out method is technically uncomplicated, economical, wasteful of time in locating trouble, and subject to operator competence. (The operator may by-pass a step or align a stage improperly thereby affecting its performance reliability.)

11.4.2 Semiautomatic Method

Semiautomatic operation relieves the operator of certain routine tasks. This action enables the operator to locate problem areas which may be too costly or difficult to mechanize. As a result, overall operator time is reduced and, therefore, a less skilled operator can be used. Failures are recognized sooner and action is initiated to reduce down-time of the receiver more quickly.

The semiautomatic method of FRIS has the following advantages and disadvantages:

a. Adds moderately to the technical complexity of the receiver
b. Adds moderately to receiver cost
c. Reduces receiver down-time
d. Involves less operator competence than required by manual operation.

11.4.3 Completely Automatic Method

The need for a completely automatic operation is dictated by the requirement that the receiver have a high availability time and remote control operation. The attending operator is required only to replace modules when directed by a computer. (Operator skill is reduced to a minimum.)

The completely automatic method is the most technically complicated and the highest in cost, but it provides rapid and complete failure reporting and fault isolation. It is less subject to operator competence.

11.5 DESIGN EMPHASIS

The failure reporting system is contingent upon the complexity of the device under test. The most desirable approach (and the one to examine initially) is the completely automatic FRIS using dynamic checking. The procedure then will be to readjust the FRIS system to be compatible with the needs of the receiver.

11.5.1 Checkout Requirements

The FRIS equipment must enable an operator to restore receiver operation within 6-minutes of failure. This time was derived from consideration of a MTBF of 1000 hours and a receiver availability of 0.9999.

The FRIS must be capable of self-checking to insure availability.

Because the receiver contains more than 300 modules, the time involved in one mechanical scan would be approximately 1 minute. This time can be reduced by sampling functions instead of modules. In this manner one test point can suffice for approximately 4 modules.

However, all modules will include provision for monitoring if completely automatic check-out is required in the future.

11.6 TYPE OF TESTING

The most desirable testing procedure would be the inclusion of dynamic testing equipment. Many different types of test and montoring equipment will be required for testing the receiver. Since dynamic testing equipment has not been included in the design such equipment will be studied during follow-on.

11.7 ISOLATION TEST CIRCUIT

A test circuit which will not affect the operation of the circuit under test is needed. Failure of the test circuit must not interfere with receiver operation. This condition requires that a short, open, or noisy condition of the test circuit be isolated from the circuit under test. Such a circuit is possible and is extremely simple. Another, desirable characteristic is measurement of the tolerance, margin, or circuit performance. The test circuit will not show this function, but provision for adjusting the limits of failure will be included.

To present all the modules in parallel form would use 900 transistors, 600 diodes, and approximately 2400 additional components. Of course, electronic scan can be used, but the number of components would increase over the parallel arrangement since an isolation circuit must be provided and some type of sampling circuit included.

It appears that some reduced testing will be necessary if the checkout equipment reliability is to be better than the receiver.

By careful test-point application to the receiver module, a minimum number of test points can be obtained. Approximately 70 such points are required for this receiver. Fewer test points would seriously jeopardize restoration time. The scheme used requires that (in some failures) perhaps one module or several modules must be replaced to restore receiver operation.

11.8 PRESENTATION OF FAILURE

Several methods are available to indicate that a failure has occurred. Audible and a visual alarm are activated on the receiver reporting panel. Other methods include a matrix presentation and diode logic to identify the module or modules which have failed, and a mechanical scan system which prints out the defective module or modules.

By following a planned routine checkout precedure, it is possible to avoid the cost of a mechanical scan system and reduce matrix presentation by eliminating the diode logic. The result is that the display panel will indicate module function by lamps. An unlit lamp represents a failed condition. This type of presentation will be used in this receiver.

11.8.1 Sensing

Wherever practicable, the voltages will be scaled to less than 1 volt. From Figure 11.1 it can be seen that a 1 megohm resistor isolates the stage under test from the test circuit. Malfunctions in the test circuit will not affect receiver operation. The sensing circuit operates a differential amplifier, and any change from nominal -- either an increase or decrease -- will turn off the operate light.

11.8.2 R-F Circuits

Part of the output of the various r-f circuits (STALO, r-f multiplier, VCO,) will be rectified and monitored by the test circuit of Figure 11-1.

11.8.3 Feedback Circuits

The phase/frequency lock operation can be monitored by measuring the impedance looking back into the circuit. These loop systems are self-regulating, the impedance looking into the circuit will vary from locked to unlocked conditions. For phase lock operation, the impedance at lock can vary 3 to 4 times less than the unlock situation. Use of this information can be made to indicate normal operation. An audio oscillator feedback ratio with this impedance as part of the circuit can be adjusted to prevent oscillation. However, unlocked, the ratio will be high enough to cause oscillation. The phase-lock signal can be rectified and handled as in Figure 11-1. (A similar scheme is available for frequency-lock operation).

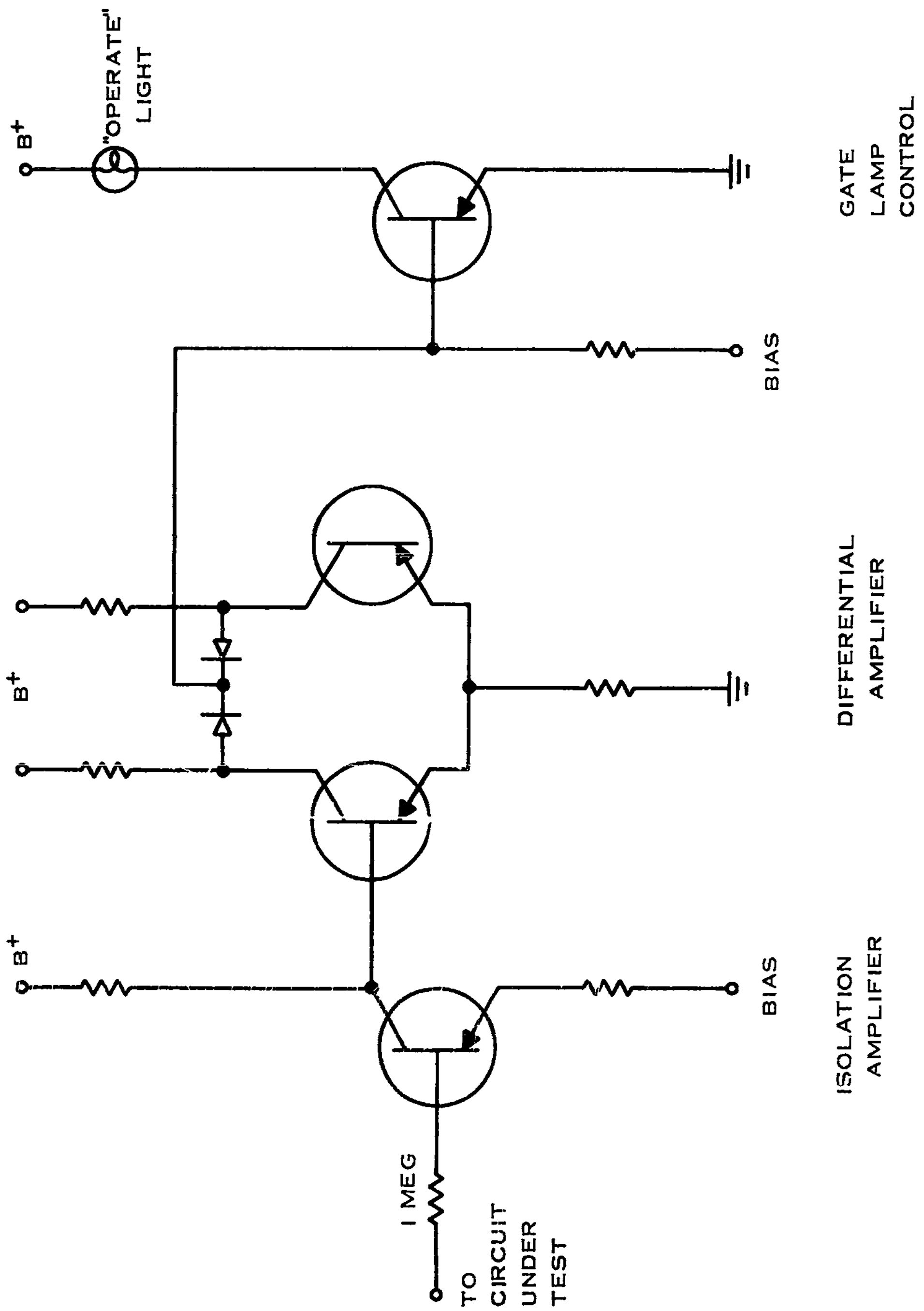


Fig. 11-1 Typical Warning Circuit Configuration

11.8.4 Synthesizer

The synthesizer contains phase-locked dividers. These circuits will be monitored as outlined for the phase-lock circuits. The standard mixers and amplifiers will be monitored as outlined in the r-f circuits.

11.8.5 I-F Amplifiers

The I-F amplifiers will not be monitored on a continuous basis as the previously mentioned circuits. Only when a malfunction is reported by the remaining system (e.e., phase or frequency lock) can it be checked. A manual switch can inject a signal from the synthesizer into the I-F and the detected signal would reveal the gain of the I-F.

11.8.5 R-F Front End

Normal performance of the front end is also determined by injecting a test signal. Since the r-f portion is mounted on the antenna, it makes this test physically difficult to accomplish. A simple test oscillator will be required at the antenna to verify receiver operation. The test control unit is operated from the receiver end since it might be desirable to determine whether the receiver is operating or if the received signal has faded into the noise background.

11.8.7 Power Supply

All power to the receiver power supply and the antenna will be monitored.

11.8.8 Sweep Circuits

A manual check on the sweep circuits will be provided. A part of the sweep circuits will be rectified for monitoring purposes.

11.9 TESTING PROCEDURE

The operator will visually scan certain portions of the display panel starting from the input. (The STALO will be called the initial input.) The first area will display the STALO and distribution amplifiers.

If all lamps are functioning, the operator proceeds to the next block which is the synthesizer.

The next area to be examined is the r-f multiplier. If the failed module has not been indicated at this point, the operator injects a test signal into the I-F. If all lamps function, the operator can inject the signal into the front-end and determine whether the input signal dissappeared or the front-end failed.

This system will not provide information regarding the isolation of a failed cable, defective switch meter or similar type devices. The probability of failure for these devices are very low. Physical adjustments, such as, switch actuation or drawer pulling might encounter failures, but this is not likely during a critical time.

11.10 REMOTE OPERATION

Provision for remote operation and failure detection have been included. In the future, several of these receivers could be operated from one location. If this is the case, one semi-skilled operator could direct several unskilled maintainance operators to replace defective modules when required. Prealignment of all modules removes the possibility of poor adjustment by the operator during replacement.

11.11 PROCEDURE IN RECEIVER OPERATION RESTORATION

Table 11-1 shows the restoration procedure when notification of an alarm condition occurs.

The modules will have additional test points available. Given a short training period, an operator could determine which 3 modules are defective, and avoid the delay of replacing two good units.

TABLE 11-1

RESTORATION PROCEDURE

NOTE:

When the alarm is actuated, the following procedure is used. In all cases of "Off Light," press the lamp test position to assure that the test circuit is operating properly.

Step	Function
1. Check "Reference Signal Section" on the panel	1. (a) All lights "ON". - Go to Step 2. (b) One or more lights "OFF" Check "STALO" - IF OFF replace STALO 0° - Replace module #_____ 90° - Replace module #____ 5 Mc A_1 - Replace module #_____ A_2 - Replace module #_____ A_4 - Replace module #_____ A_5 - Replace module #_____
2. Check "Synthesizer Section	2. (a) All light "ON". Go to Step 3. (b) One or more lights OFF Check: If following order Replace modules in order given. Input — Module# 9.0 — _____ . — _____ . — _____ . — _____ . — _____ 10.0 — _____

TABLE 11-1 (Cont'd)

Step	Function
3. Check "R-F MULTIPLIER" Section	3. (a) All lights "ON". - Go to Step 4. (b) Check in following order, replace module in order given. Input Module#____
4. Press "IF TEST"	4. (a) If all lights then come "ON". - Go to step 5. (b) Check in following order. Replace module in order given.
5. Press "FRONT END" Test:	5. (a) If all lights then come "ON". - Input signal not present. (b) Check in following order. Replace module in order give.

11.12 MODULAR REPALCEMENT

The time limit of 0.1 hour for receiver restoration places stringent requirements on availability and identification of modules. The modules must be designed to allow minimum time to remove a unit or units and replace them with operating equipment.

The module number assigned must be coded for easy identification by the operator. This identification would take the form of, for example, 4LL R 1-3, meaning 4th Drawer, Lower Side, Lower Right Side, No. 1 Unit of 3 Units. These 3 units are reported by the same lamp. Another possibility could be through color code identification. Each drawer could be color coded and have a number assigned to the module to permit rapid module location.

The mounting of hardware and connectors must be of the "quick disconnect" variety. Finally, the replacement module must be stocked in the immediate area and stored in a prescribed method so as to facilitate rapid identifacation and use by the operator. The isolation test circuit has provisions for testing the "high-low" limits of a module.

Provision for injection of a test signal to verify receiver operation is an additonal capability that enables the operator to guard against signals which have either disappeared or have insufficient level.

The failure reporting system will permit an operator to detect a failure, replace the defective module, and return the receiver to operation within the time limit of 0.1 hour.

11.13 SUMMARY

The failure reporting system consists of continuous monitoring of approximately 90 percent of the key functions. The remaining 10 percent are checked as required.

When a malfunction occurs, the procedure for repair is as follows:

a. Check test equipment (push-button operation quickly verifies operation of the checkout equipment).

b. Compare "OFF" lights against a chart to determine defective modules.

c. Replace defective module and recheck operating lights, for normal performance.

SECTION 12

ANGLE AND DOPPLER TRACKING CONSIDERATIONS

12.1 GENERAL

One of the requirements of the receiver is that it operate in angle and doppler tracking systems. This is necessary for the receiver to be truly multipurpose. The considerations necessary for the above are discussed in the ensuing discussions.

12.2 ANGLE TRACKING

12.2.1 General

There are two kinds of tracking systems of concern and they are conical scan and monopulse. Those methods will be discussed separately.

12.2.2 Conical Scan

In the conical scan system, an antenna-feed nutator amplitude modulates the received signal. During the tracking mode (not during acquisition in angle), the modulation index is very small and usually has negligible effect on the received signal in case other detection is contemplated.

The amplitude modulated tracking signal is detected from the input signal carrier using conventional or phase lock A-M detectors. The A-M signal is then phase compared with a reference signal in a phase detector. The phase detector output is the antenna servo input error signal.

The conical scan signal frequency varies from 10 cps to 40 cps for mechanical nutation. For hybrid conical scan monopulse systems employing electrical balanced modulators, the modulating frequency can be several hundred or thousand cps. In this case, a phase detector is also used.

In the multipurpose receiver, both conventional and phase lock detectors are available. The output of the multipurpose receiver will be the AM detected signal. The auxiliary phase detector with its necessary filtering was not added to the receiver design as this is properly part of the servo system.

Another signal is needed in the conical scan system to help the antenna servo know that a signal is being received and to prevent angle search of the antenna. The rectified power from the conventional detector or the in lock or AGC signal from the phase lock detector can be used and both are available from the receiver.

12.2.3 Monopulse

The monopulse receiver consists of a reference channel and two error channels. Therefore three idential I-F channels are required. To obtain the servo error signal, the error signals are phase compared to the reference signal. It is necessary to carefully control the relative phase shift of the reference and either error channel. Usually 10 or 20 degrees relative phase shift is permitted. Ten degrees was specified for this receiver.

The reference channel I-F amplifier signal can be fed directly to the phase detector or it can be filtered by using a phase lock loop and the VCO output can be fed to the phase detector. Both methods will be incorporated into the receiver design. (In the actual phase lock design, the VCO signal is fed to a mixer and a STALO reference is fed to the phase detector).

In the case of a wide-band F-M signal, the phase shift on the signal can be more easily controlled if FMFB is employed reducing the required I-F amplifier bandwidth. In this case the frequency lock VCO is fed to the phase detector.

For monopulse and conical scan, the AGC must maintain the reference channel I-F amplifier idential to the variation in gain of the reference channel I-F amplifier.

12.3 DOPPLER TRACKING

A phase-lock loop is used in the doppler tracking receiver to represent the receiver signal relatively free from receiver and input noise.

In the doppler receiver, the local oscillators are all phase locked to the carrier or consist of very stable frequency sources.

The VCO output and local oscillator signals are fed to a unit called a doppler extractor. The doppler extractor (among other processes) forms a doppler frequency signal referenced to a bias frequency of a value usually between 50 kc to 200 kc.

In the multipurpose receiver, phase lock and STALO's are used for the LO signals. All of the mixers are not phase locked. However, all of the LO and VCO signals are available as outputs to any desired doppler extractor (not part of the receiver design) or for any other purpose.

SECTION 13
RADIO FREQUENCY INTERFERENCE

13.1 GENERAL

Successful operation of the multipurpose receiver requires that each individual functional unit or module must meet design specifications, and that when these functional units are integrated, system operation must be free of all types of spurious interferences and unintentional feedback generated within the receiver. Introduction of a spurious signal causes misinterpretation of data and jeopardizes receiver operation. The designer must take into serious consideration problems of radio frequency interference (RFI).

With the ever-increasing complexity in electronic equipment used in space communications, such as this multipurpose receiver, it is necessary that all man-made interference be reduced to a level less than the internal noise level of the receiver. Suppression of spurious interference is even more important with the advent of low noise pre-amplifiers that may be used with this receiver. In planning the components layout and circuit design, it is most important not to rush the initial period.

13.2 DEFINITIONS

RFI may be defined as any electrical disturbance generated in a system causing undesirable response within the system or interference with the operation of other nearby electronic systems. The sources include signals from harmonic generators, switching transients, stepping motors, and servo motors. RFI sources may be predicted by careful examination of circuit parameters, equipment characteristics and operating frequencies. It is easy to predetermine the location and level of signals. Steps can then be taken to allocate frequencies and separate system functions for minimum interaction.

13.3 TYPES OF INTERFERENCE

Interference may be classified into two types: (1) conducted, and (2) radiated.

13.3.1 Conducted Interference

Conducted interference results from common power supplies and common ground returns. Adequate r-f filtering of the B+ line inside each module is absolutely necessary. At higher radio frequencies, the chassis can no longer be considered an equipotential ground plane of zero inductance and the arrangement of the component parts, modules, and grounding points becomes extremely important.

13.3.2 Radiated Interference

Radiated interference results from a current passing through a conductor and setting up a field about the conductor. Shielding is used to prevent a signal or noise energy on a wire from being radiated. Multiple shield coaxial cables are required for high level r-f signals, such as those from the synthesizer multiplier chain. The shield must never be used as a return conductor, since current flowing in the surface of the shield can cause radiated R-F energy. Radiation from components inside a module creates a major problem in shielding. The degree of electromagnetic shielding depends on the type of thickness of the shielding material. The relationship may be shown to be as follows:

$$S = R + A$$

where S = total amount of shielding (db)

R = reflection loss (db)

A = absorption loss in the material (db)

The magnitude of these losses depend on the frequency involved. An r-f field has both electronic and magnetic components. Magnetic field predominates in r-f coils. Since reflection losses for magnetic fields are small for most materials, the shielding depends primarily on absorption losses. For a one-mil thickness of copper, dissipation is

5 db at 1 Mc and 5 db increase per decade of frequency increase. Thus, for 5 mc signal having a power level of 100 mw, about 200 db shielding is required (10 db below noise level). Absorption loss is about 7 db per mil at 5 mc. Therefore, $\frac{200}{7} \approx 30$ mil copper sheild is required. This shows that any shield which is structurally sound will be thick enough for shielding radio frequencies. However leakage through shield cover gaps and wire connectors actually creates the shielding problem. Therefore, wire connectors should be well shielded and, if necessary, potted with lossy material.

13.4 DESIGN CONSIDERATIONS

Some design considerations regarding RFI have been suggested by sprague Electric Company and should be noted. They are summarized as follows:

<u>Component Selections</u>

(1) Transformer selected for use in the system should provide complete electrostatic sheilding between primary and secondary windings

(2) The use of d-c motors or any motor using commutator brushes should be avoided in the servo system

<u>Circuit Design</u>

(1) Relay coils should have effective surge-damping elements associated with time

(2) Leads to relay and switch contacts which are normally open, should be bypassed or filtered when entering or leaving an enclosure in which interference sources exist

(3) All leads carrying dc should be filtered or decoupled at their point of entrance or exit in an enclosure which contains a source of interference

(4) B+ leads feeding pulse circuits should be decoupled near the point of pulse generation. This applies to gate generator, sweep oscillator, Schmidt trigger, etc.

(5) The addition of ferrite beads in high gain R-F circuits is necessary.

(6) All high level R-F cables should have a double shield

(7) Power and control leads subject to frequent switching transients should be routed or shielded so as to minimize inductive or capacitive coupling with other wiring

(8) High and low level stages in individual compartments should be isolated. This will assist greatly in providing effective shielding

Material, Process, and Mechanical Considerations

(1) Keep ground leads to chassis as short as possible

(2) I-F chassis should be constructed in such a way that they are, in effect, waveguides below cutoff, affording 60 db stage-to-stage isolation. If space requirement is restricted, partition between stages should be installed

(3) When possible, Iridite should be used in place of anodizing for protectively treating metal surfaces. Iridite provides an excellet metal-to-metal r-f bonding in assembling modules and chassis parts.

13.5 SUMMARY

Electrical and physical design shall meet the requirements of radio frequency interference suppression. High level transients due to circuit switching must be damped or suppressed by means of diodes, resistors, capacitors, or other devices. Inductive fields due to relay solenoids and stepping motors should have magnetic and electric sheilds to prevent radiation. R-f sources such as reference oscillators and synthesizer, should not be housed near the I-F amplifier input stages or where it may cause leakage into the I-F amplifiers Input and output stages of the I-F amplifier must be separated by a distance so that it will not become a closed servo loop and cause oscillation or instability All r-f sources generated or processed by the receiver, regardless of any specific origin, shall not be propagated out of the receiver either by radiation or by conduction.

SECTION 14
POWER SUPPLY REQUIREMENTS

14.1 GENERAL

Several sources of power supply are needed to obtain optimum performance. There should be separate power supplies for signal processing circuits and for solenoid switches and motors to reduce transient interference. A minimum of 30 volts is necessary to operate the transistors in the synthesizer and harmonic generator units so that the required r-f power can be generated.

14.2 PERFORMANCE SPECIFICATIONS

14.2.1 30-Volt Power Supplies

a. Output voltage: 0 - 30 v (two required for plus & minus polarities)

Output current: 0 - 3 a

b. A-C Input: 105 - 125 VAC 60 cps ± 10 cps

Operating ambient temperature and duty cycle: Continuous full load $0^{\circ}C$ to $+50^{\circ}C$ ambient.

c. Regulation:

(1) Line-0.01 per cent variation in d-c voltage for a 20 per cent variation in a-c input voltage

(2) Load-0.01 per cent variation in d-c output voltage from no load to full load.

d. Ripple and Noise:

Less than 0.5 millivolt rms.

e. Output Impedance:

Less than 0.002 ohm dc to 100 cps

Less than 0.01 ohm 100 cps to 1 kc

Less than 0.1 ohm 1 kc to 100 kc

Less than 1 ohm 100 kc to 1 mc.

f. Transient Response:

There shall be no output voltage overshoot on turn-on, turn-off, or power failure. Output voltage shall be constant within regulation range. Regulation shall be recovered within 100 μsec if load is changed from no load to full load or full load to no load.

g. Overload Protection:

Instantaneous electronic lockout plus continuously variable current limiting from 20 per cent of full load to 100 per cent of full load.

h. Temperature Range:

These power supplies shall be rated for continous duty over a temperature range from 0° to 50°C.

i. Remote Programming:

The output voltage shall be accurately controlled from a remote point.

j. Physical Dimensions:

Each 30-volt d-c power supply shall fit in a 19-inch rack. Panel height shall not exceed 3-1/4 inches, and chassis depth shall not exceed 14 inches.

14.2.2 <u>100 Volt D-C Power Supply</u>

This supply is used primarily for the checkout unit lighting system; high degree of regulation is not required.

a. Line Input: 105 - 130 vds
60 cps ± 10 %

b. Output Voltage: 100 vdc

c. Output Current: 300 ma

d. Regulation:

(1) Line: ±5 % variation in d-c output for 20 % variation in a-c input

(2) Load ±5 % variation in d-c output voltage from no load to full load.

e. Overload Protection:

There shall be a current-limiting device allowing direct shorting of the output terminals without damage to the supply.

f. Output Ripple: 10 mv maximum.

g. Internal Impedance: Less than 1 ohm.

h. Operating Temperature: 0° C to 50° C

Physical Dimensions:

Maximum height	5	inches
Maximum width	8	inches
Maximum depth	12	inches

14.2.3 <u>28-Volt D-C Power Supply</u>

This power supply is primarily used for switching devices. High degree of regulation is not required.

a. Line Input: 105 - 130 vac 60 cps ± 10 %

b. Output Voltage: 28 vdc

c. Output Current: 10 amperes

d. Regulation:

(1) Line: ±2.5 % variation in d-c output voltage for 20 % change in input voltage

(2) Load: ±2.5 % variation in d-c output voltage from no load to full load.

e. Overload Protection:

There shall be a current-limiting device allowing direct shorting of the output terminals without damage to the supply.

f. Output Ripple: 10 mv maximum.

Internal Impedance: less than 0.1 ohm.

g. Operating Temperature: 0° C to 50° C.

h. Physical Dimensions:

Max height 5 inches

Max width 8 inches

Max depth 12 inches.

14.2.4 <u>400 Cycle as Source</u>

A 400 cycle ac source is required for the control system using servos.

SECTION 15
PHYSICAL DESIGN

15.1 GENERAL

In order to achieve the versatility and adaptability derived from standardization, the receiver system is designed for mounting in a standard 19- x 70-inch rack (see Fig. 15-1). Each mechanical and electrical unit of the receiver (with the exception of a few off-the-shelf items) will be designed to advanced packaging techniques.

The following receiver characteristics and requirements governed the selection of packaging:

a. Varied physical size, shape, and mounting of receiver components

b. A required, constant ground plane for obtaining optimum results

c. A requirement for almost absolute shielding of r-f modules to stop r-f interference, leakage, and spurious response from transients outside the r-f electronics.

Because of the above governing factors, it was not possible to use customary modular design for the multipurpose receiver. Instead, a design has been developed that includes the advantages of standard modular design while providing the flexibility, constant ground plane, and maximum r-f shielding required by the receiver.

15.2 DESIGN DESCRIPTION

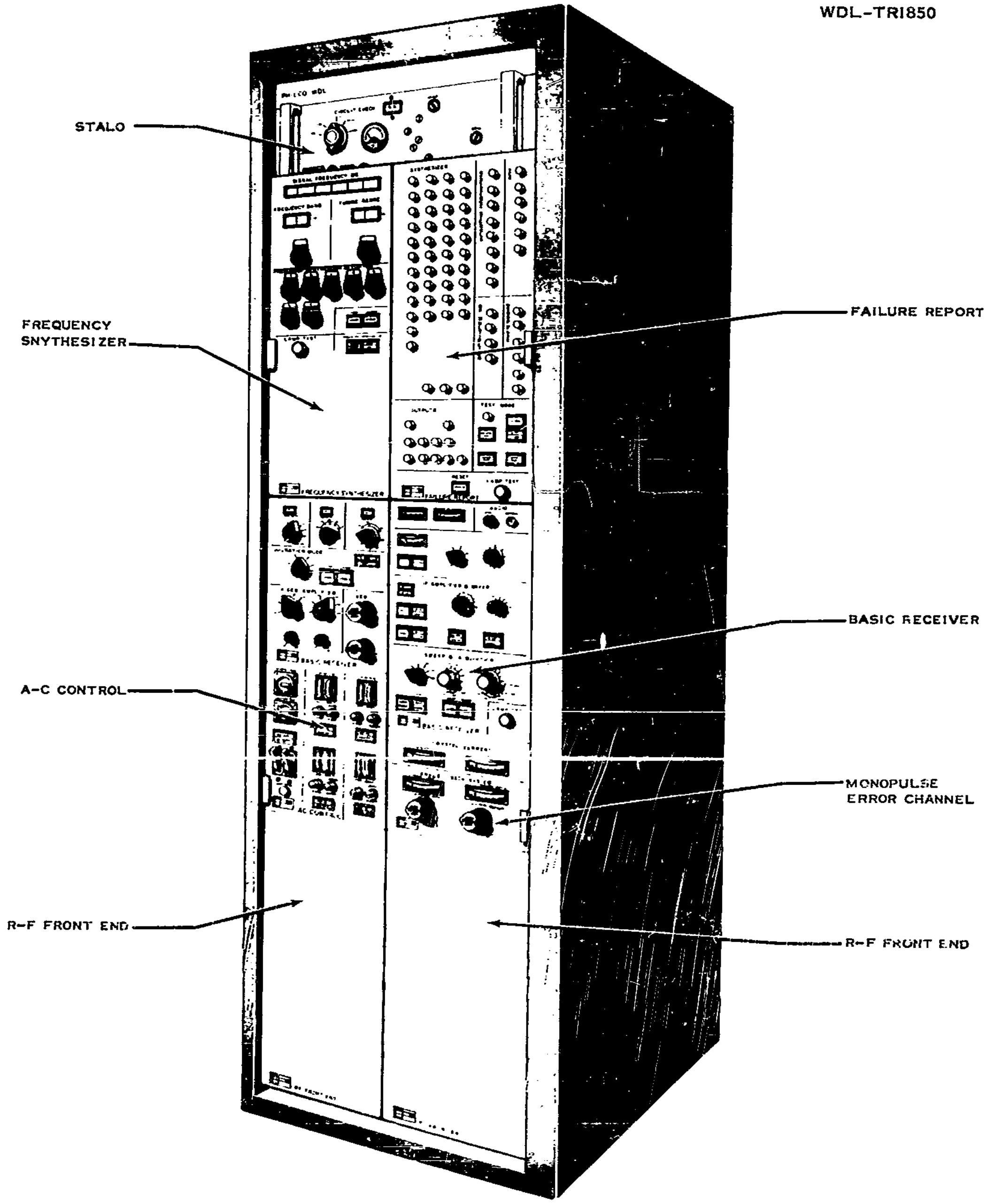


FIG. 15-1 MULTIPURPOSE RECEIVER

15.2.1 Chassis Design

Figure 15-2 illustrates arrangement of vertical drawers to achieve easy and immediate access to the modules and interconnecting cabling. The latch that is used disengages the drawer from the cabinet with a normal arm pull, and the drawer moves outward. The drawer shown on the left top of Fig. 15-2 illustrates how plug-in modules are installed. The drawer shown on the right middle of the same figure shows the r-f cable interconnections between the modules of the drawer. (Power leads and grounding are provided in addition to r-f cabling.) All drawers are supported by Jonathan slides.

15.2.2 Module Tray Design

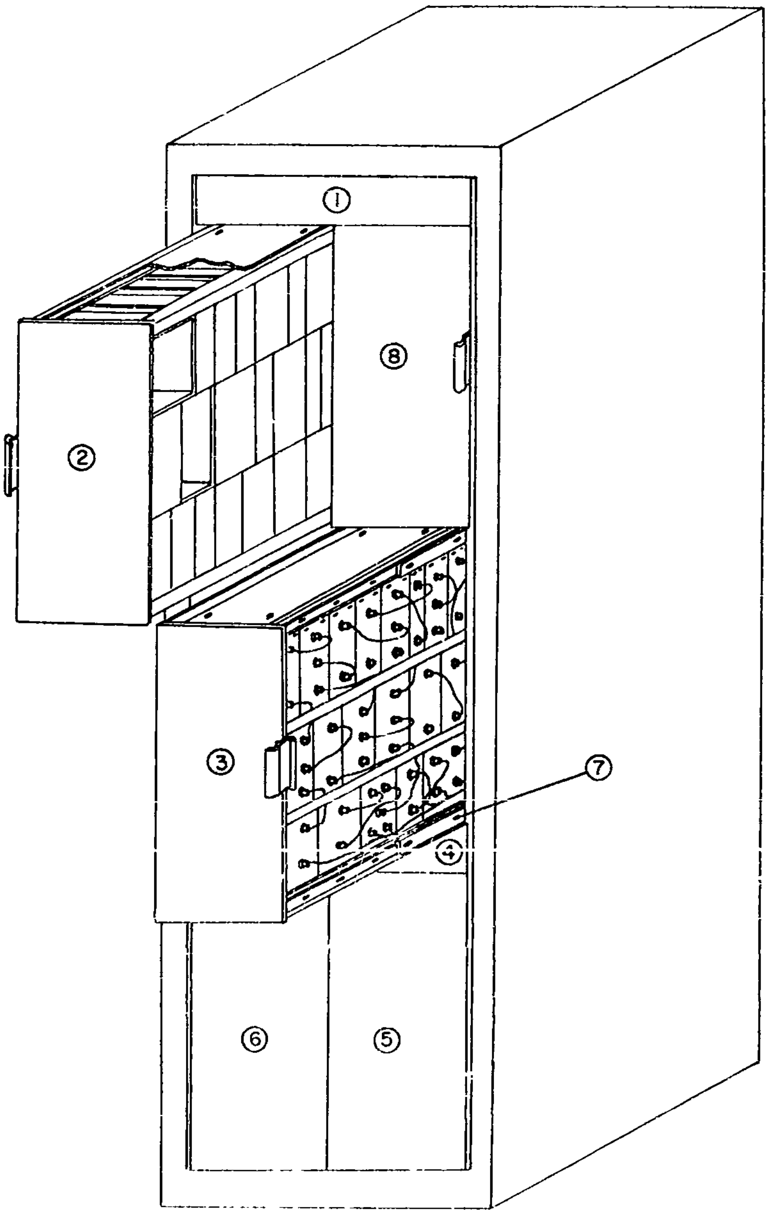
Each drawer supports three module trays. A typical tray is illustrated in Fig. 15-3 to show features of construction.

Module compartments are made of a number of standard parts as shown in Fig. 15-4 and 15-4A. These standard parts are tin plated, assembled with four tie-rods, and dipped in a hot oil bath to fuse the tin and bond all joints to insure maximum r-f tightness.

Separators are included in the assembly of the tray when r-f protection is a consideration; otherwise, separators are not used.

The module plug-in connectors are integrated in the tray assembly by adaptor plates. Data handling modules will require a typical printed circuit plug-in connector, and r-f modules will require an adaptor plate which supports the r-f fittings.

Individual plug-in r-f fittings will be used in order to eliminate r-f leakage problems which may develop in the use of multi-pin, plastic plug, r-f connectors.



1. STA-LO
2. SYNTHESIZER
   FAILURE REPORTING
   HARMONIC GEN
3. BASIC RCVR
4. MONOPULSE
5. RF FRONT END
6. RF FRONT END
7. CHASSIS SLIDE
8. FAILURE REPORTING

Fig. 15-2 Arrangement of Vertical Drawers

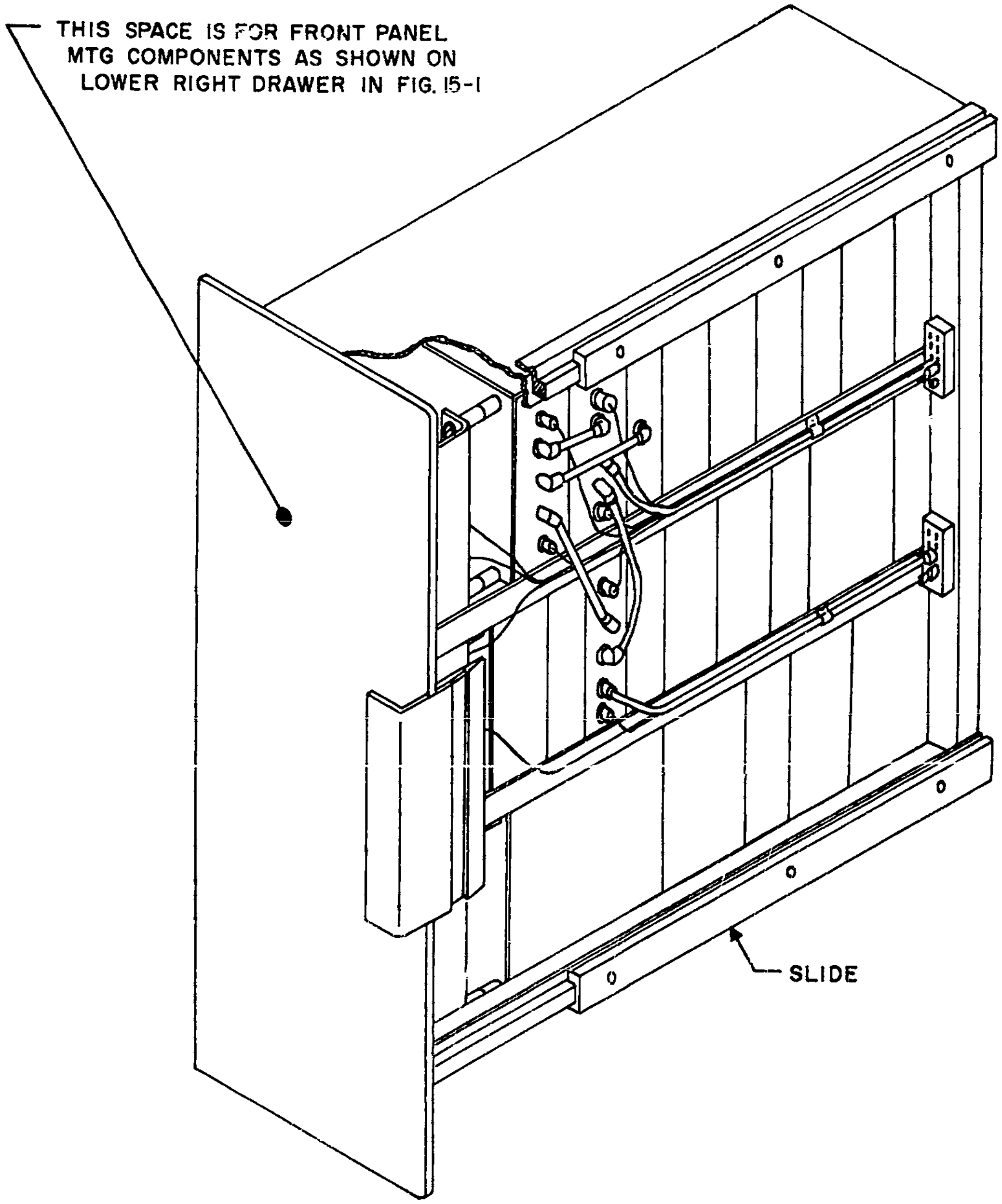


Fig. 15-3 Typical Module Tray

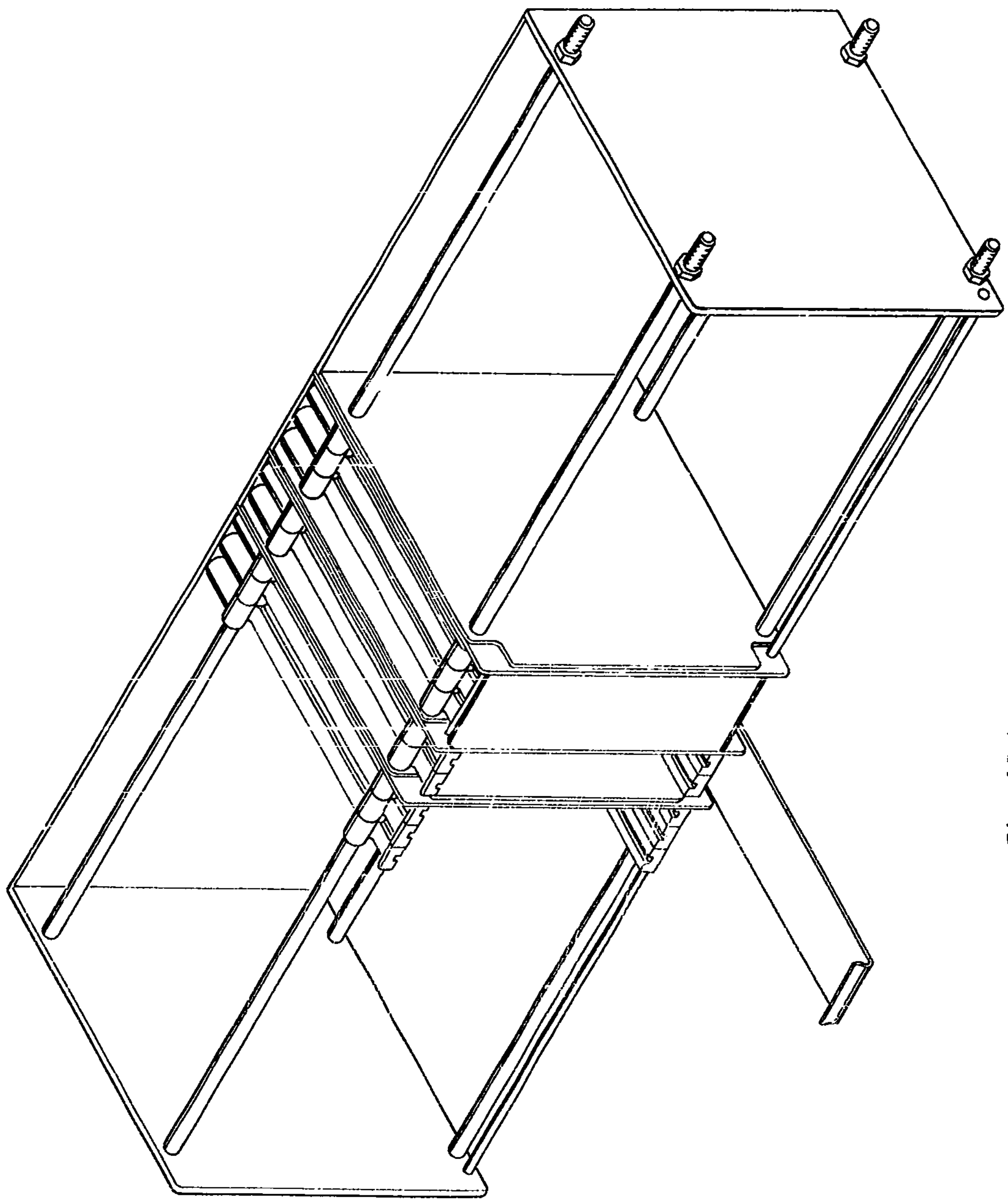


Fig. 15-4 Typical Module Compartment

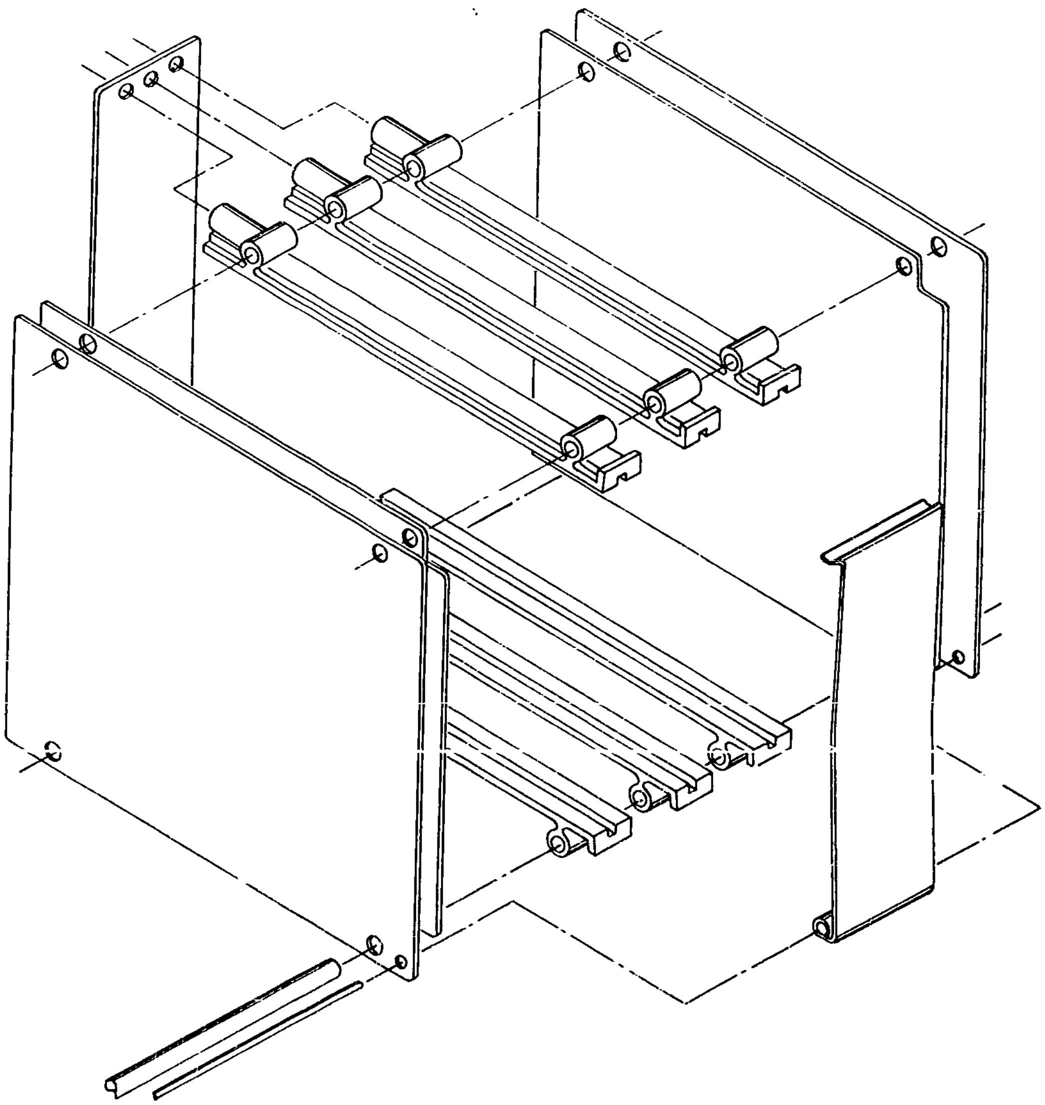


Fig. 15-4A Standard Part Application for Module Compartments

The front enclosure of each r-f module is a curved cover of springy material pinned in place at one end and provided with a clip on the opposite end. The cover is closed and latched by the clip. As it closes, the cover is forced to straighten as it bears metal-to-metal with mating edges of the module compartment. The cover is a design option item as it is needed to enclose r-f modules, but is not necessarily needed for enclosure of logic and data handling modules.

15.2.3 Module Design

In this modular design, specific restrictions and freedoms of the arrangement of the electronics are available.

The design of any of the modules is based on a board which has standard perimeter dimensions, plug connector, mounting, and extracting devices. This provides an area within which complete freedom is available for the arrangement of components, wiring, shields, adjustment screw locations, and test points. The available area on each board is, therefore, fixed, but the volume is flexible within limits.

A typical r-f module, which can be plugged directly in the receiver drawer, is illustrated in Fig 15-5 When component and inter-stage shielding prove insufficient for r-f protection within the all metal cubicle, the module will be completely enclosed by metallic covers, as shown in Fig. 15-6

Cooling of temperature sensitive components in critical circuits is accomplished by sinking the thermal load into the metallic component mounting deck from which it is dissipated by conduction to the exterior walls of the metallic module cubicle. Convection currents within the module assist in accomplishing heat transfer. Because of the low power consumption of r-f modules compared to the surface area of the exterior walls of the module cubicle, the module cubicle structure can be taken as the ultimate heat sink. It is to this end that a finned external surface is used. This thermal treatment is comparable to that provided presently in receivers and is considered adequate for all components contemplated.

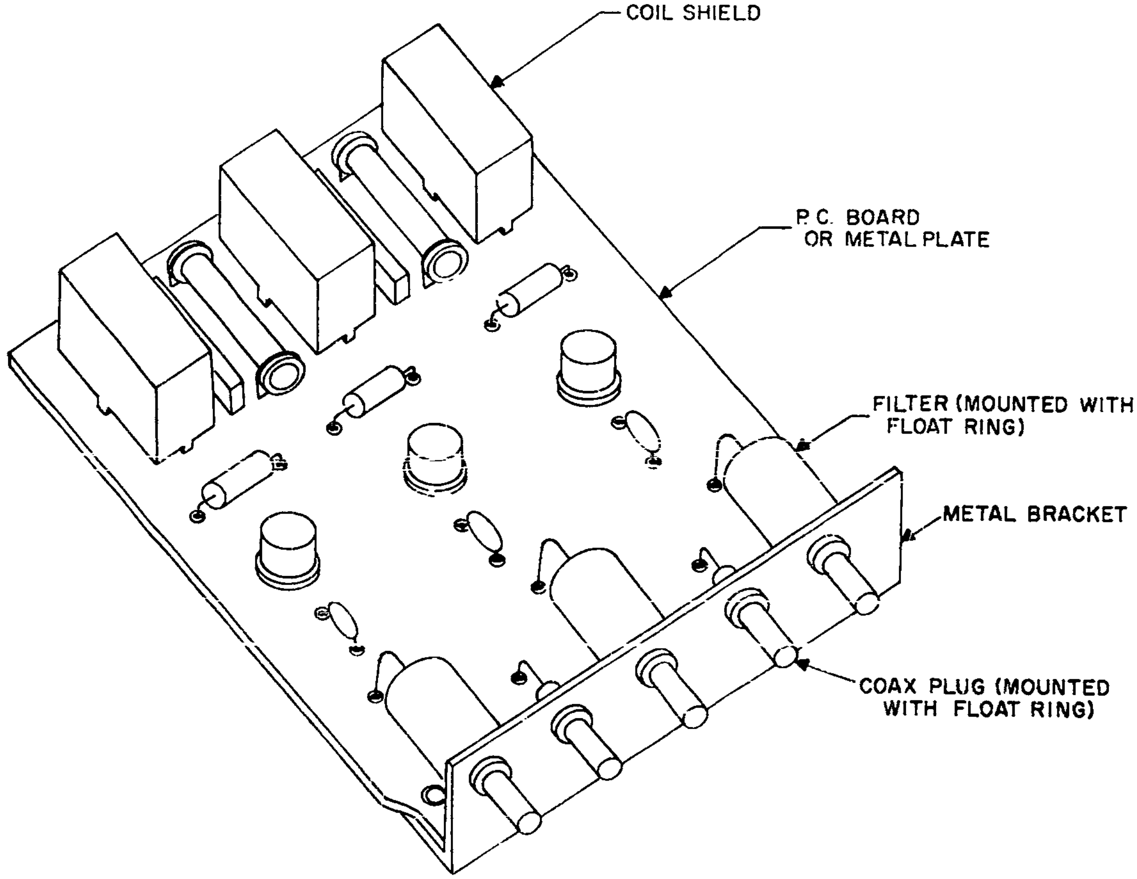


Fig. 15-5 Typical R-F Module

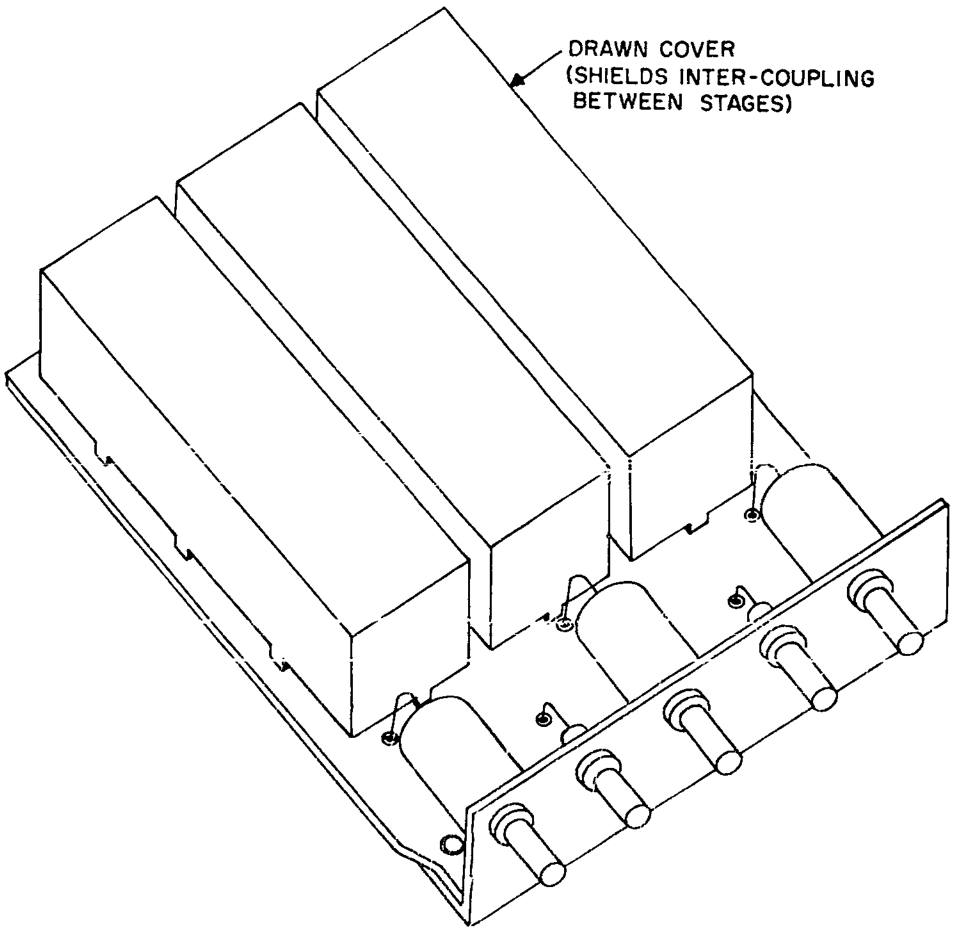


Fig 15-6 Typical R-F Module with Covers Installed

The largest heat source is the power transistors in the harmonic generator package where as much as 10 watts may be dissipated in a module, adjacent modules may dissipate 1 watt, and the remaining modules may dissipate 1/4 watt. This heat load results in a temperature rise of 150°F at the outside walls of the cubicle housing the power transistors. The accumulated Δt's across joints and mountings of the transistor is approximately 16°F.

The sum of the normal room temperature 75°F, plus the temperature rise 15°F, plus the 16°F Δt's equals 108°F; which is the expected operating temperature of the power transistor. Thus, the use of internal miniature spot blowers, external blowers and exotic devices can be reserved for unusual components which, conceivably, could be necessary in some future application.

15.2.4 Availability Features

Some of the features which affect availability are inherent and self-evident with the modular approach, while others are attained by carefully incorporated features. The following table lists the hardware characteristics which must be optimum to obtain the highest availability, and the means of attainment:

CHARACTERISTIC	MEANS OF ATTAINMENT
Immediate readout of failure	Readout located on front panel and capable of continuous monitoring.
Quick access to failed electronics	Pull chassis or drawer by pull-latch and slides arrangement
Quick removal and replacement	Snap off cover from defective module, pull and replace module, resnap cover, close drawer.

The need for wrenches or screwdrivers has been eliminated as convenient, quick latches and snaps reduce the availability down-time to the minimum.

15.2.5 Accessibility Features

Accessibility is closely related to the same parameters as availability, but extends to other activities such as initial checkout of equipment and inclusion of the inputs and outputs of additional equipment into the receiver for future system changes. The receiver proper is arranged into vertical drawers permitting accessibility to any module and associated connector terminal that can be reached from the front of the receiver. The back of the receiver cabinet is hinged for standard availability.

15.2.6 Adaptability and Versatility

The modular approach to receiver packaging has the following features of adaptability and versatility:

a. Because the chassis and drawers are a 19-inch standard width and RETMA increments in height, any standard cabinet can be used to accommodate the modular chassis and drawers by bolting in the appropriate standard brackets.

b. A receiver can be updated in the field by plugging in a new module. This is made possible by insuring that future improvements in receiver components or circuit arrangement will be implemented by the same modular hardware as described above.

c. Extensive modification of existing equipment in standard cabinets can be carried out readily because of the modular arrangement, which has been extended to include not only the module itself but also to "baskets" of modules, a chassis of three "baskets" each, or drawers of "baskets" arranged vertically. All of these have predesignated cable and connector locations that permit cabling by charts showing "from - to" connections in terms of the pre-established designators.

15.2.7 Marking Technique

All electrical components and mechanical parts will be marked as specified in MIL-STD-130. Thus, each module will have a characteristic designation. Each module's position in a receiver will be marked with the appropriate module's designation at the cubicle where it should be plugged in. Inadvertent insertion of a module into a wrong cubicle will result in failure of the system to operate, but will not result in damage to the equipment.

SECTION 16

RELIABILITY ASSESSMENT OF FINAL DESIGN

16.1 INITIAL ASSUMPTIONS

This receiver design is intended to provide coverage for a number of possible operational modes. Only selected circuits will be active when a particular satellite is being tracked, i.e., when the receiver is operating in a given mode. Because of this factor, it would reflect an extremely pessimistic viewpoint and probably be far from the real situation to quote figures for the complete equipment when trying to determine the probability of success or availability for a particular satellite pass. The figure of interest to a user is the degree of dependability he can expect from the equipment when it is installed in his station, tracking the satellites he is assigned to track, and receiving the information he has to handle. In accordance with this concept, the reliability analyses presented herein reflect the reliability status and probable failure rates for a number of the most probable operational modes.

16.2 ORIGIN OF FAILURE RATE DATA

The base failure rates used for this analysis were taken from tabulated standard data in WDL Reliability Standards 99-501. These standards include, and are generally compatible with, the standards set forth in the widely used Rome Air Development Center (RADC) Handbook*, with additions to extension of certain tables by WDL Reliability Services engineers. These changes, brought about by qualification of new parts and improvement of existing product lines, are part of a continual updating process designed to keep WDL reliability practices abreast of the state-of-the-art. As test results reported by part manufacturers are verified by WDL reliability personnel, the standards will be revised accordingly.

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* Reliability Notebook, RADC TR-58-111, published by the U. S. Department of Commerce, October 1959.

16.3 GUIDELINES FOR ESTIMATION

In selecting the parts and estimating the failure rates for this receiver, the following basic assumptions were made:

- o All elements will be MIL-Spec or better
- o Passive elements (with noted exceptions) will be derated to 20 to 30 per cent rated values
- o Load and heatsink factors in the design will be such that the junction temperature of germanium devices will not exceed 65°C; the junction temperature of silicon devices will not exceed 125°C.

16.4 BLOCK DIAGRAM ANALYSIS

For the purposes of reliability analysis the multipurpose receiver circuits were divided into seven major functional arrangements, as shown in Figs. 16-1 through 16-7. These diagrams are presented to establish a basis for the discussions to follow. Although failure rates integral to each functional block are shown for comparison purposes, mere totaling of the figures given would be misleading since all of the blocks will never be used in any one operational mode. Expected failure-rate figures for the various operational modes are presented in the material to follow. The rates given are in per cent per 1000 hours.

16.5 MODE ANALYSIS

Twenty-four of the most probable operational modes were selected and analyzed (see Table 16-1). It is believed that these modes will handle the receiver requirements for major satellite systems now in existence or expected in the foreseeable future.

The preliminary analysis for the "basic-system" (i.e., no redundant elements) receiver indicated that no redundant techniques would be needed to considerably exceed the 1000 hour design goal for MTBF. All failure-rate calculations presented here are based on the basic-system assumption. As a result, the MTBF expectancies quoted will tend to be somewhat conservative; this factor should be kept in mind when reference is made to these figures.

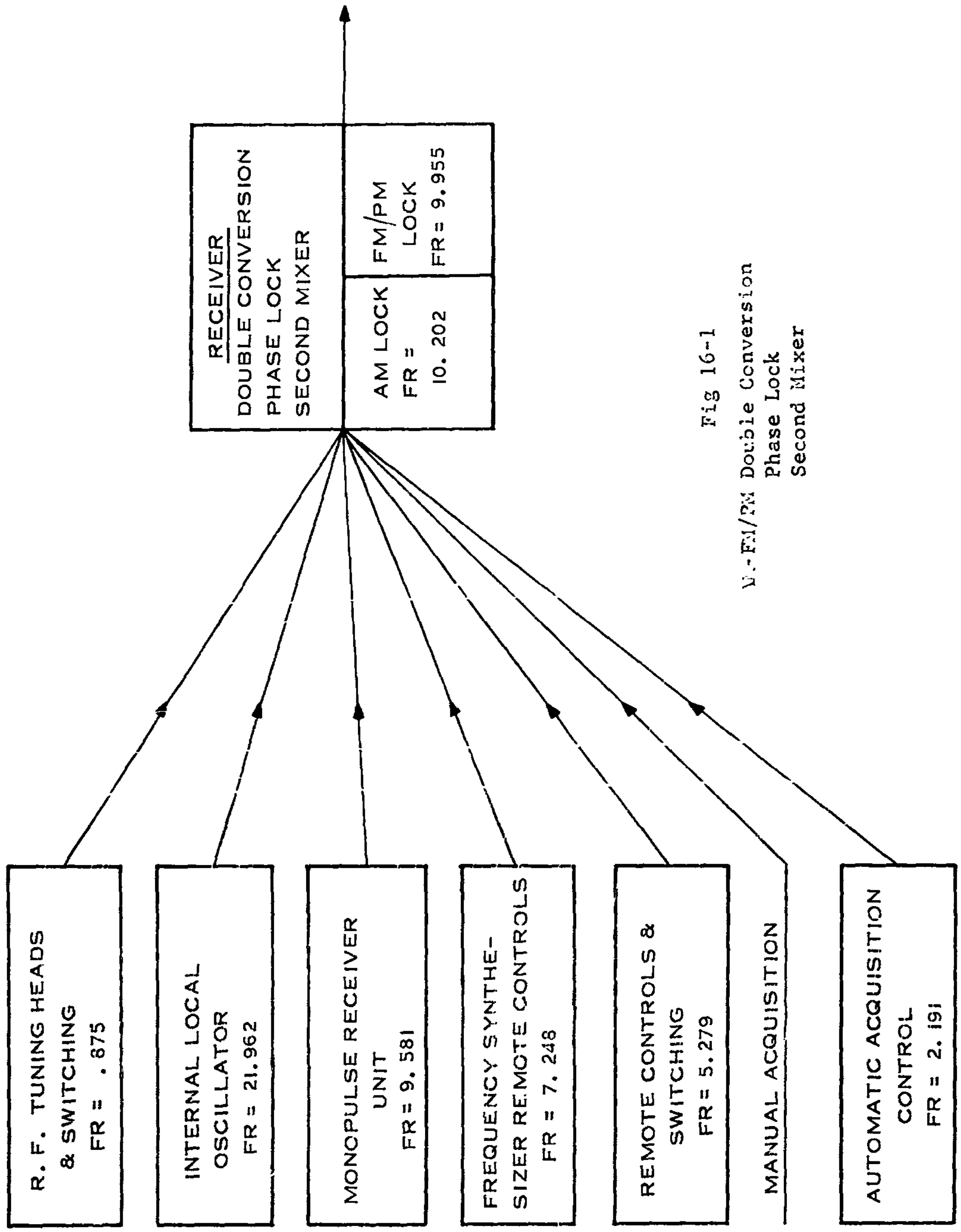


Fig 16-1

M.-FM/PM Double Conversion
Phase Lock
Second Mixer

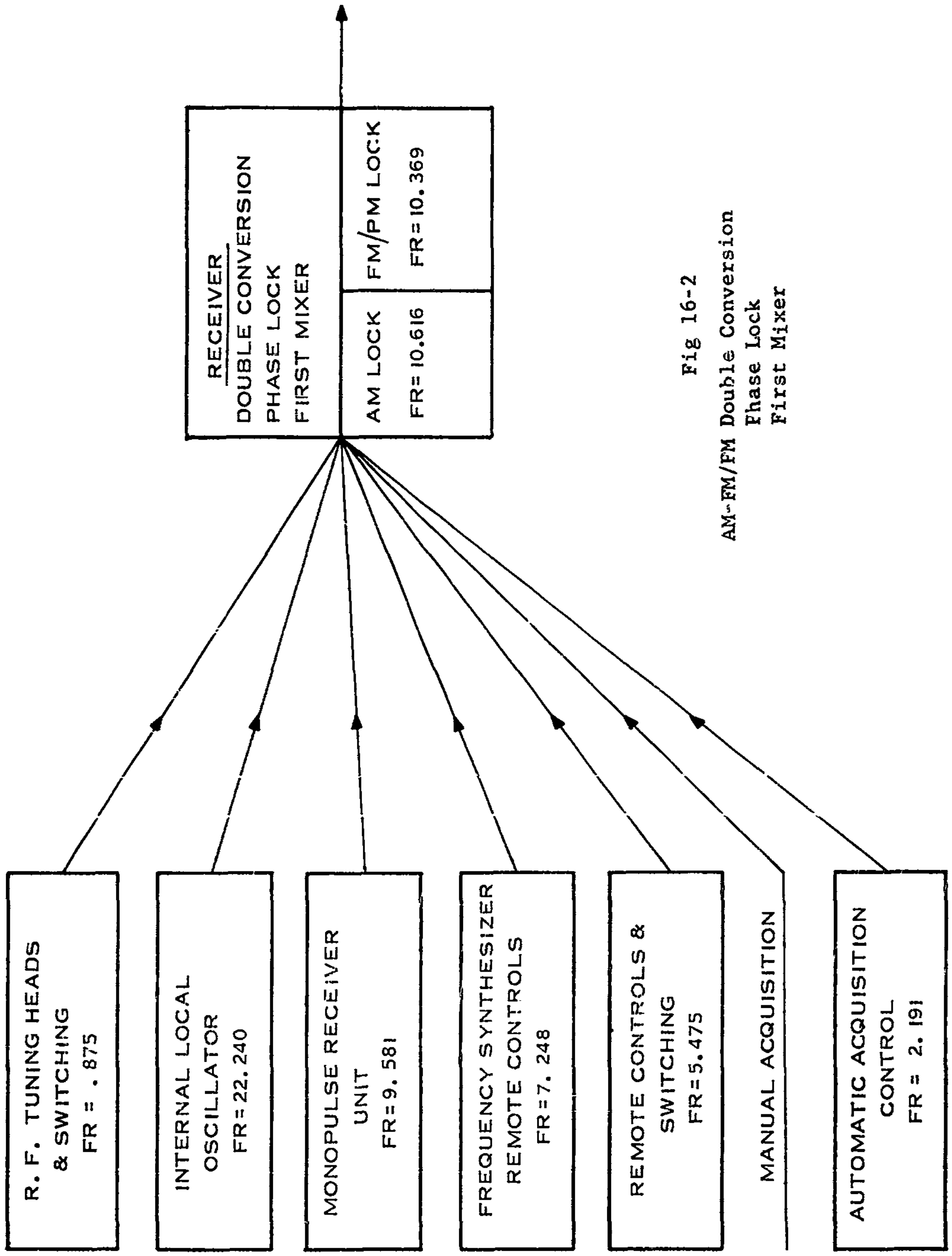


Fig 16-2
AM-FM/FM Double Conversion
Phase Lock
First Mixer

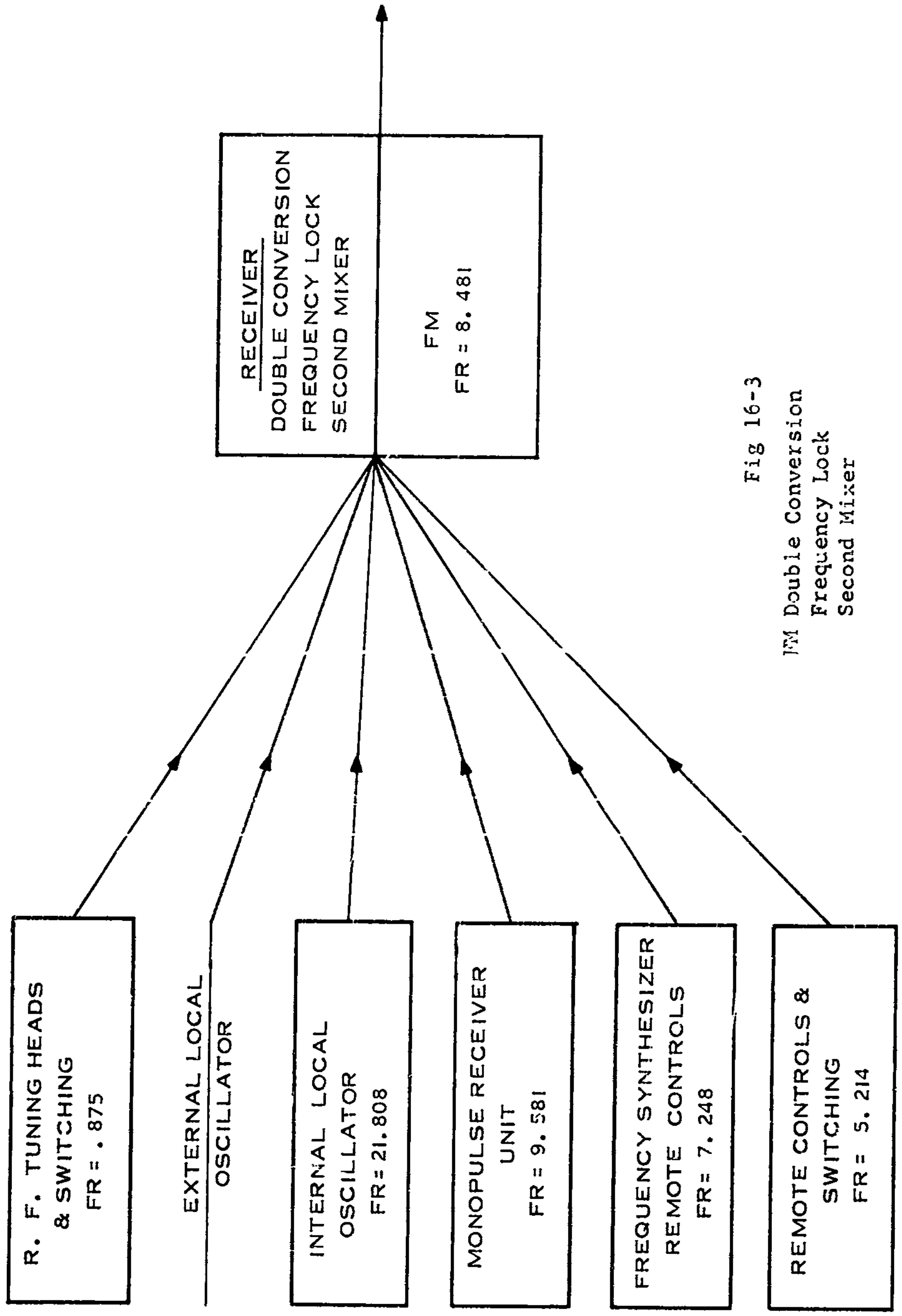


Fig 16-3
FM Double Conversion
Frequency Lock
Second Mixer

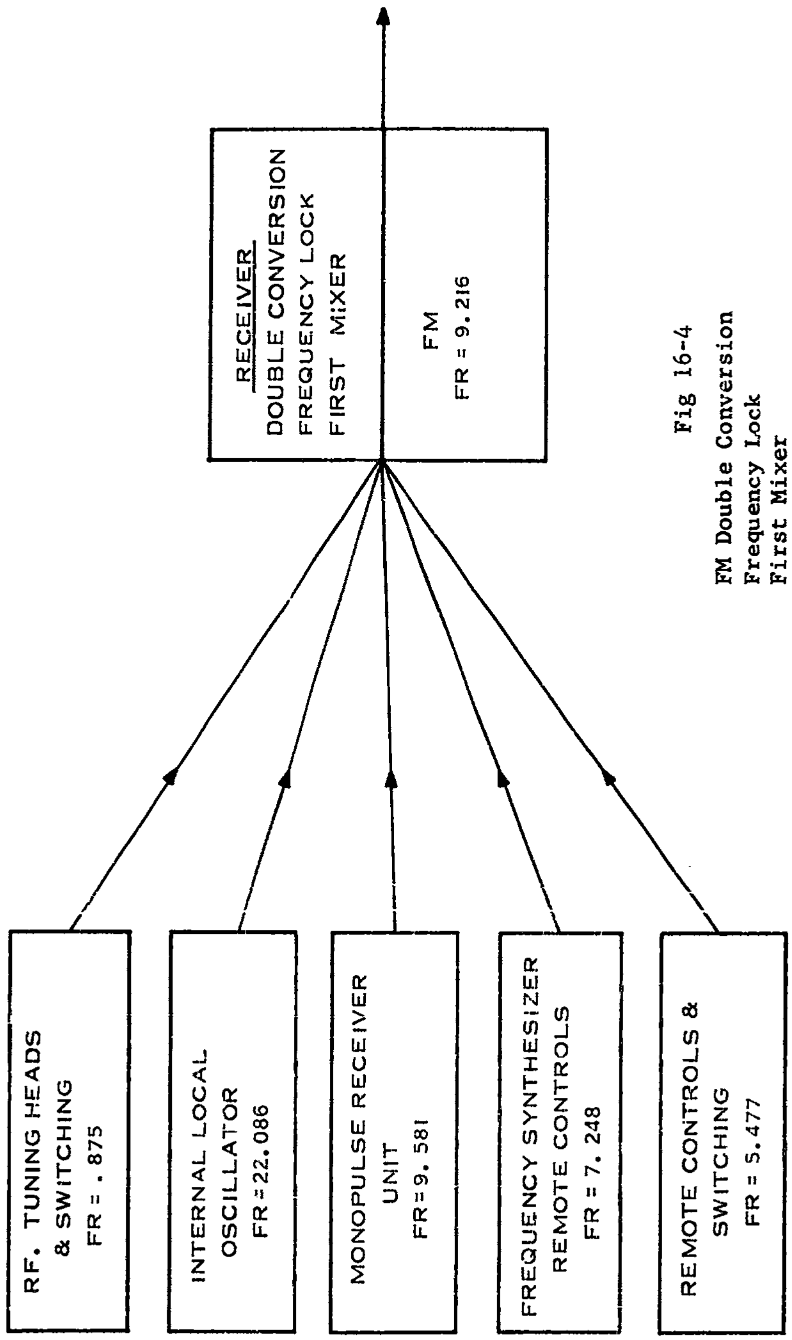


Fig 16-4
FM Double Conversion
Frequency Lock
First Mixer

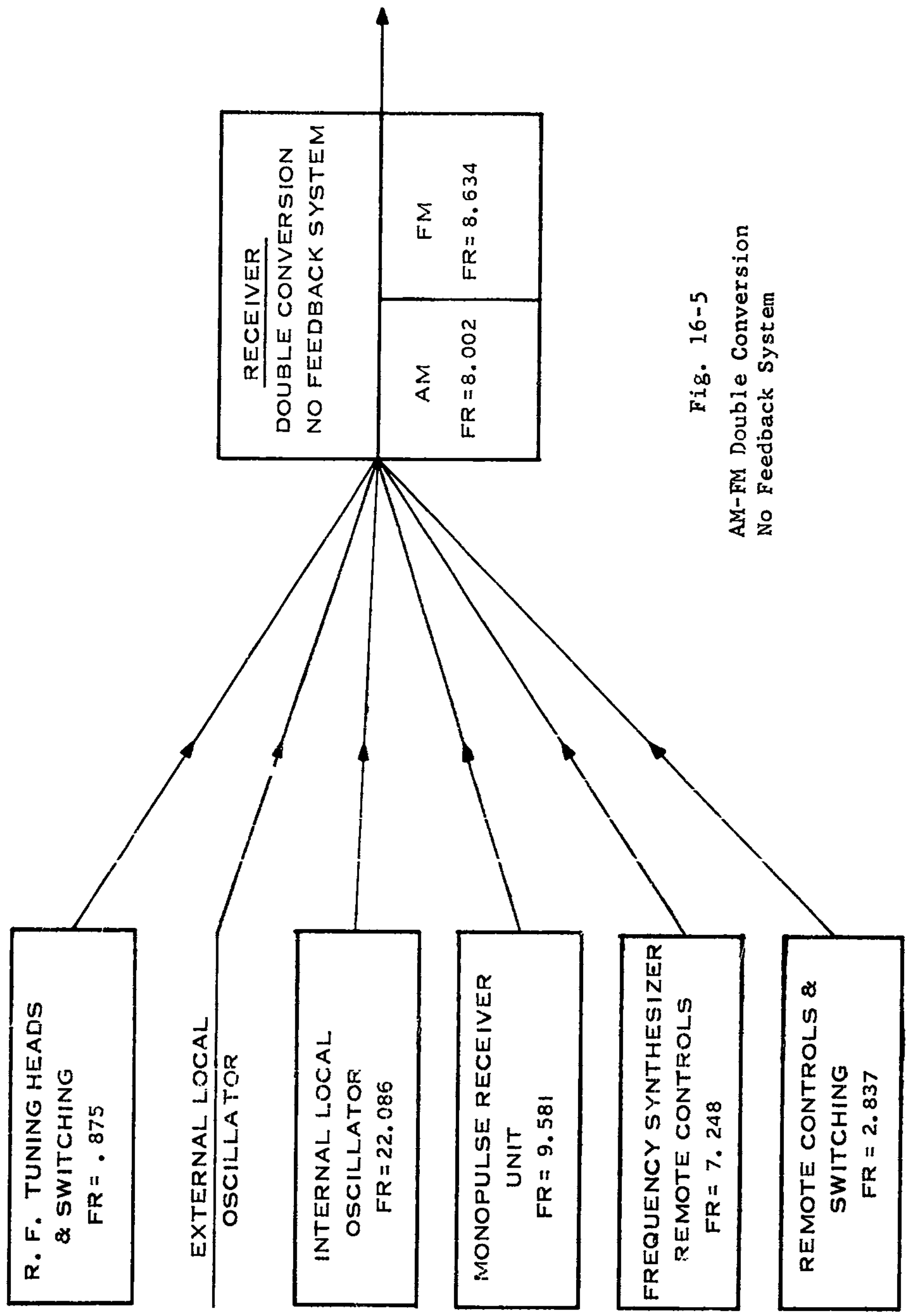


Fig. 16-5
AM-FM Double Conversion
No Feedback System

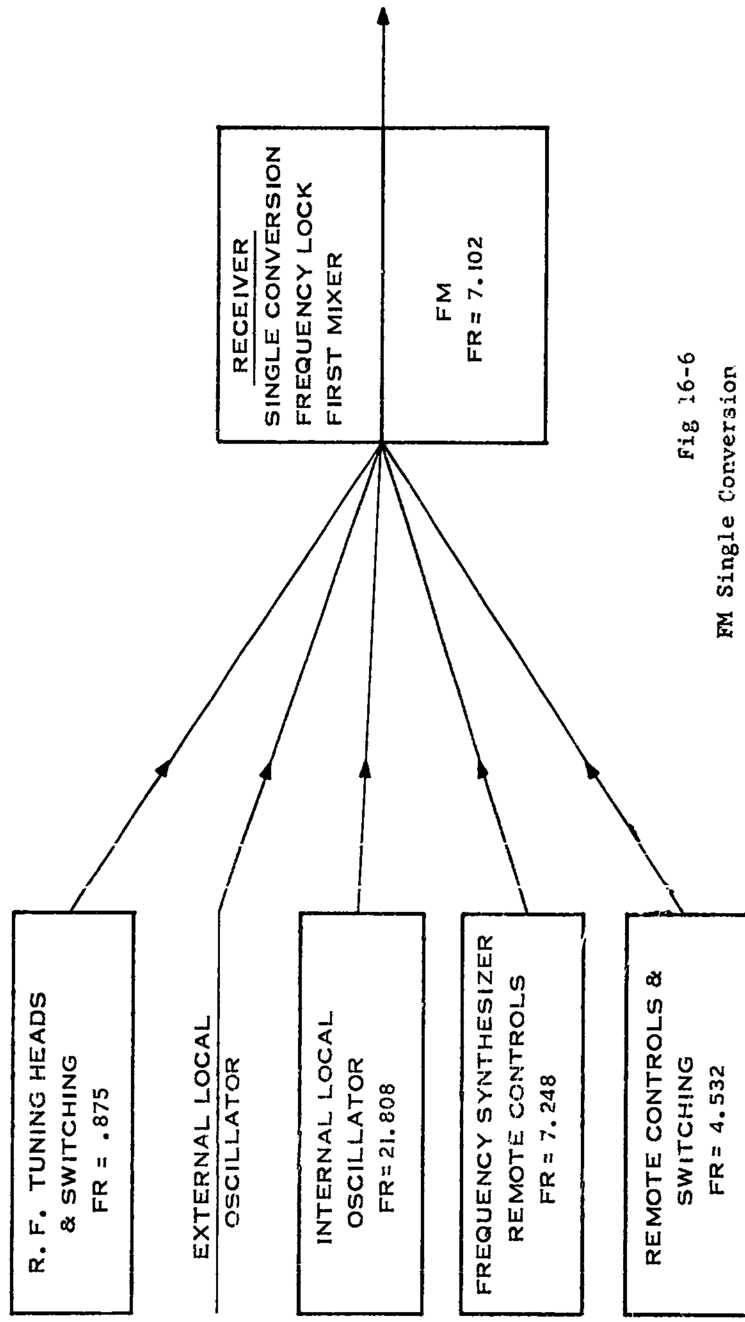


Fig 16-6

FM Single Conversion
Frequency Lock
First Mixer

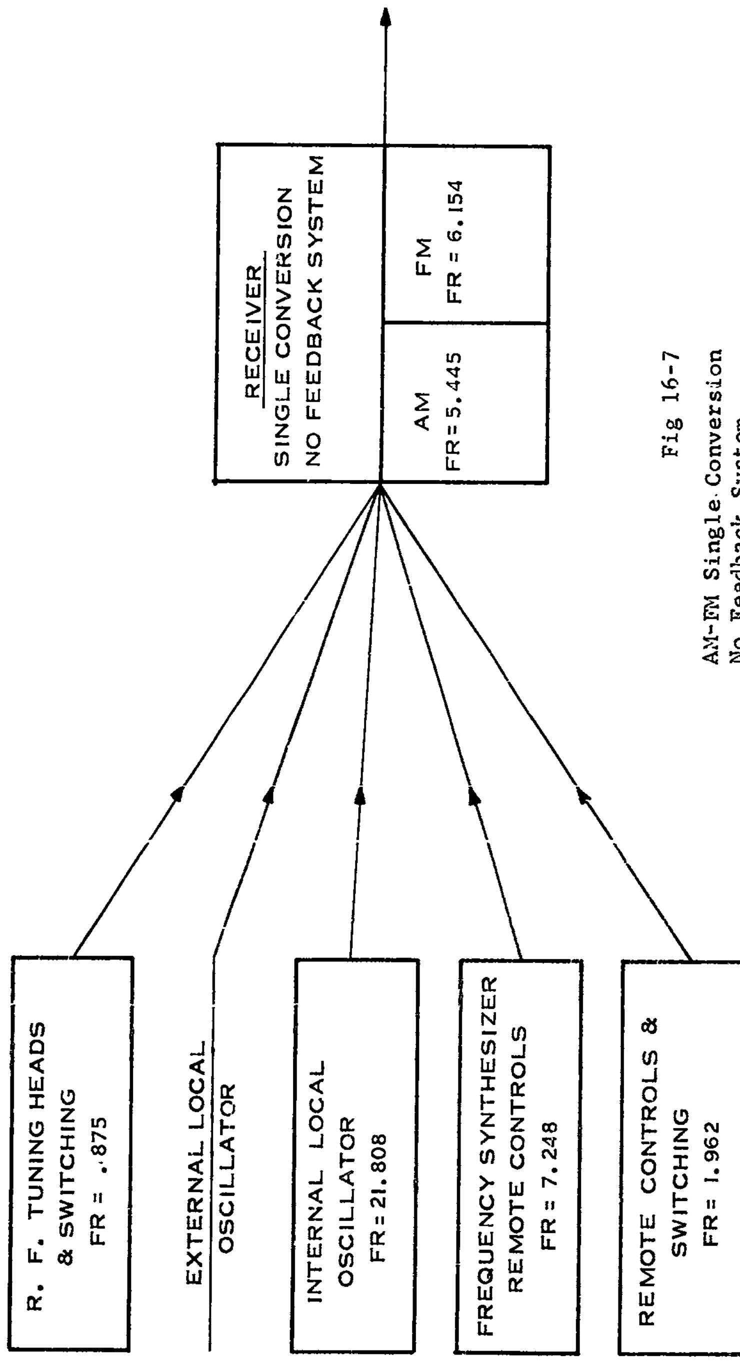


Fig 16-7
AM-FM Single Conversion
No Feedback System

TABLE 16-1

MULTIPURPOSE RECEIVER ANALYSIS:
MODES OF OPERATION

ANALYSIS	SINGLE CON.	DOUBLE CON.	PHASE LOCK FIRST MIXER	PHASE LOCK SECOND MIXER	FREQ. LOCK FIRST MIXER	FREQ. LOCK SECOND MIXER	WITH MONOPULSE RECEIVER	WITH EXTERNAL LOCAL OSC.	ACQ. MODE	TOTAL FAILURE RATE AT 25°C IN %/1000 HRS.	MTBF HOURS
1	AM								NONE	37.338	2678
2	AM							X	NONE	8.282	12.077
3	FM								NONE	38.047	2628
4	FM							X	NONE	8.991	11.123
5	FM				X				NONE	41.565	2405
6		AM							NONE	41.048	2436
7		AM					X		NONE	50.629	1975
8		AM						X	NONE	11.714	8539
9		AM					X	X	NONE	21.295	4694
10		FM							NONE	41.680	2399
11		FM					X		NONE	51.261	1950
12		FM						X	NONE	12.346	8097
13		FM					X	X	NONE	21.927	4549
14		FM				X	X		NONE	53.207	1879
15		FM				X	X	X	NONE	24.151	4140
16		FM			X		X		NONE	54.483	1835
17		FM/PM Lock	X				X		Manual	55.788	1792
18		FM/PM Lock	X				X		Automatic	57.979	1724
19		AM Lock	X				X		Manual	56.035	1784
20		AM Lock	X				X		Automatic	58.226	1717
21		FM/PM Lock		X			X		Manual	54.900	1821
22		FM/PM Lock		X			X		Automatic	57.091	1751
23		AM Lock		X			X		Manual	55.147	1749
24		AM Lock		X			X		Automatic	57.338	1743

TABLE 16-2

MULTIPURPOSE RECEIVER ANALYSIS:
MODES OF OPERATION WITHOUT THE MONOPULSE RECEIVER UNIT

ANALYSIS	SINGLE CON	DOUBLE CON	PHASE LOCK FIRST MIXER	PHASE LOCK SECOND MIXER	FREQ. LOCK FIRST MIXER	FREQ. LOCK SECOND MIXER	WITH EXTERNAL LOCAL OSC	ACQ. MODE	TOTAL FAILURE RATE AT 25°C IN %/1000 HRS.	MTBF HOURS
1	AM							NONE	37.338	2678
2	AM						X	NONE	8.282	12.077
3	FM							NONE	38.047	2628
4	FM						X	NONE	8.991	11.123
5	FM				X			NONE	41.565	2405
6		AM						NONE	41.048	2436
7		AM						NONE	41.048	2436
8		AM					X	NONE	11.714	8539
9		AM					X	NONE	11.714	8539
10		FM						NONE	41.680	2399
11		FM						NONE	41.680	2399
12		FM					X	NONE	12.346	8097
13		FM					X	NONE	12.346	8097
14		FM				X		NONE	43.626	2292
15		FM				X	X	NONE	14.570	6863
16		FM			X			NONE	44.902	2227
17		FM/PM Lock	X					Manual	46.207	2164
18		FM/PM Lock	X					Automatic	48.398	2066
19		AM Lock	X					Manual	46.454	2152
20		AM Lock	X					Automatic	48.645	2055
21		FM/PM Lock		X				Manual	45.319	2206
22		FM/PM Lock		X				Automatic	47.510	2104
23		AM Lock		X				Manual	45.566	2194
24		AM Lock		X				Automatic	47.757	2093

The preliminary analysis for the "basic-system" (i e., no redundant elements) receiver indicated that no redundant techniques would be needed to considerably exceed the 1000 hour design goal for MTBF. All failure-rate calculations presented here are based on the basic-system assumption. As a result, the MTBF expectancies quoted will tend to be somewhat conservative; this factor should be kept in mind when reference is made to these figures.

Each of the operational modes is listed and the functional blocks involved in operation in each mode are called out. The listing is followed by a tabulation which shows the total failure rate and MTBF for each mode. It is well to note that the worst mode, Number 20, has an MTBF of 1717 hours, well above the design goal. The composite MTBF representing an actual utilization profile will of course be better than the worst-case condition.

In actual construction it is anticipated that a number of items, especially those with high contributions to the overall failure rate, will be paralled whenever circuit, weight and packaging conditions permit. A case in point is the rotary stepping switches to be used for certain switching requirements. Since the principal failure mode for these devices is an open circuit, it is anticipated that one or more redundant sets of contacts will be put in parallel for each essential circuit path. Use throughout the receiver of this principle alone will result in a significant increase in MTBF.

In some cases, factors other than part failure rate dictate the use of redundant elements. Among these factors are logistics, access and restore time, and probability of mission success requirements for a given mission. If it is absolutely essential that the equipment be operative for a given portion of certain short-period missions, and the access and restore time is a significant portion of the pass time, a redundant element would be indicated even though the element to be paralleled is in itself an item with a high MTBF. For example, consider

the case of an r-f head mounted on the antenna. This item has a low probability of failure in relation to the MTBF of the antenna, however, if it does fail, considerable time would be required for access and restoration. In such cases, the provision of standby units may well be justified, especially if the unit is not a costly one.

16.6 MULTIPURPOSE RECEIVER ANALYSIS MODES

1. AM single conversion - no feedback system - no monopulse receiver.
2. AM single conversion with external local oscillator - no monopulse receiver - no feedback system.
3. FM single conversion - no feedback system - no monopulse receiver.
4. FM single conversion with external local oscillator - no monopulse receiver - no feedback system.
5. FM single conversion frequency lock first mixer - no monopulse receiver.
6. AM double conversion - no feedback system - no monopulse receiver.
7. AM double conversion with monopulse receiver - no feedback system.
8. AM double conversion with external local oscillator - no feedback system - no monopulse receiver.
9. AM double conversion with external local oscillator and monopulse receiver - no feedback system.
10. FM double conversion - no feedback system - no monopulse receiver.
11. FM double conversion with monopulse receiver - no feedback system.
12. FM double conversion with external local oscillator - no feedback system - no monopulse receiver.
13. FM double conversion with external local oscillator and monopulse receiver - no feedback system.
14. FM double conversion frequency lock second mixer with monopulse receiver.

15. FM double conversion frequency lock second mixer with external local oscillator and monopulse receiver.

16. FM double conversion frequency lock first mixer with monopulse receiver.

17. Phase lock FM/PM out, double conversion phase lock first mixer - manual acquisition mode with monopulse receiver.

18. Phase lock FM/PM out, double conversion phase lock first mixer - automatic acquisition mode with monopulse receiver.

19. Phase lock AM out, double conversion phase lock first mixer - manual acquisition mode with monopulse receiver.

20. Phase lock AM out, double conversion phase lock first mixer - automatic acquisition mode with monopulse receiver.

21. Phase lock FM/PM out, double conversion phase lock second mixer - manual acquisition mode with monopulse receiver.

22. Phase lock FM/PM out, double conversion phase lock second mixer - automatic acquisition mode with monopulse receiver.

23. Phase lock AM out, double conversion phase lock second mixer - manual acquisition mode with monopulse receiver.

24. Phase lock AM out, double conversion phase lock second mixer - automatic acquisition mode with monopulse receiver.

16.7 CIRCUIT ANALYSIS

Each of the circuits to be used in the receivers were carefully analyzed. Discussion of the reliability implications and conclusions drawn from the analyses of certain key circuits and subassemblies are presented below.

16.7.1 Frequency Synthesizer

The frequency synthesizer has the lowest mean-time-to-failure of any functional unit in the multipurpose receiver. The mean-time-to-failure of the synthesizer with local controls is 6,250 hours and 4,180 hours with the proposed remote control circuitry.

The functional performance of the synthesizer permits the use of basic circuit designs, which are in current use with no known reliabiliby problems. Approximately 70 per cent of the synthesizer circuitry operates at frequencies which will permit the use of high reliability semiconductors. The failure rates for the high reliability semiconductors are an order of magnitude less than the failure rate used in computing the reliability of the synthesizer.

The other 30 per cent of the circuitry will operate in the higher-frequency regions where there are no known high-reliability transistors available for use at the present time. The transistors which will be used in the high-frequency circuitry are now being used by Philco WDL and other electronic manufacturers in VHF circuitry in space vehicle applications.

The switching in the synthesizer is accomplished by coaxial relays and rotary switches. The coaxial switching will have a mean-time-to-failure greater than 400,000 hours. The manual control rotary switching has a mean-time-to-failure of 200,000 hours. The mean-time-to-failure of the remote control system is 13,800 hours, assuming no redundancy; the use of redundant switching techniques would yield a significant increase in reliability.

16.7.2 Frequency Multiplier for First Mixer

The frequency multiplier for the first mixer is composed of eight parallel channels. A reliability analysis was performed on the channel of maximum complexity. The predicted MTBF for the channel is 110,000 hours, and the difference between the channels of maximum and minimum complexity is approximately 20 per cent. In operation, only a single channel is functional at any time. The amplifier and frequency multiplier circuitry are of the same basic design as used in solid state UHF transmitters and receivers used in high-reliability space-vehicle applications.

The frequency selection from the multiplier will be done by means of coaxial relay switching. Manufacturers' information on the general type of coaxial relay to be used in this application indicates a minimum operating life expectancy of 1,000,000 operations. In the intended application the relay is expected to be operated less than 10 times per day and at less than 10 per cent or rated power-handling capacity. Under these conditions the predicted MTBF for the coaxial relay switching in the harmonic generators is greater than 400,000 hours.

16.7.3 Stable Local Oscillator

The precision reference-frequency generator intended for use with the multipurpose receiver is a laboratory standard marketed by a reputable test equipment manufacturer. A reliability prediction was made from the actual circuit schematic, the predicted MTBF for the unit is 20,200 hours. The circuit design is all solid state.

16.7.4 R-F Heads

The r-f head is composed of a tunable preselector, mixer, preamplifier, band pass filter and coaxial switching. The tunable preselector and band pass filter will be of tuned-cavity and passive part construction. The tuned cavity and the use of less than 10 passive parts in the filter will result in an extremely low failure rate. The mixer and the i-f preamplifier will be of the same basic solid state design as is now being used in UHF receivers in space-to-ground and ground-to-space communications links. Coaxial relay switching is necessary to select the proper preselector and connect the local oscillator signal and the i-f amplifier to the selected r-f head. The above switching will require three coaxial relays. The predicted mean-time-to-failure of the r-f head is 200,000 hours or approximately 20 operating years.

The functional performance may require that the r-f head be located in the antenna. In the event of a failure of the r-f head in this location the mean-time-to-restore would be 10 to 20 times greater than the permitted time of 6 minutes. The time to restore can be reduced to a few seconds by the use of coaxial switches to switch a redundant r-f head into operation.

16.7.5 Failure Monitoring

Each of the 70 key operating circuits in the receiver will be equipped with a failure-monitoring circuit. Each monitor circuit will drive a neon indicator to report the status of the circuit being monitored. The monitoring system has been designed to be positive and fail-safe, i.e., the indicator will be lit only when the monitored circuit is in good condition. Each monitor circuit in itself has a MTBF expectancy of some 164,000 hours. In the case of monitor circuit failure, a fault will be indicated. The receiver will be equipped with a "Monitor Test" switch which will simultaneously apply test potentials to all monitor circuits, enabling the operator to determine in a matter of seconds if he has trouble in his monitor circuits. The indicator lamps are keyed to circuit locations so that the operator or repairman will be able to quickly pinpoint the trouble location. Level adjustments are provided so that gross performance degradation as well as catastrophic failures can be detected.

16.8 PARTS SELECTION AND APPLICATION

Design engineering will be assisted by Reliability Design Assurance engineers in the selection and application of each part. Part application and test reports have been accumulated from various classified Air Force space projects, Courier, Minuteman and the Inter-Service Data Exchange Service (IDEP).

16.8.1 Parts Selection

In the design and selection of parts, every effort will be made to use parts which have been tested to the environmental conditions and which comply with MIL-E-4158. High reliability parts such as those developed and presently being developed for Minuteman and classified Air Force programs will be used whenever possible.

Specification control drawings will be generated for parts which do not have adequate military or governmental specification. Specification control drawings shall list mechanical, electrical characteristics, acceptance criteria and special requirements such as "burn-in", X-ray documentation, etc. Special "burn-in" and X-ray tests are strongly recommended for the parts purchased for special high-reliability application.

16.8.2 Parts Application

The application of each part will be reviewed by a design assurance engineer, and the following factors considered:

a. The maximum allowable stead-state or transient voltage, current, temperature and duty cycle

b. Tolerances such as manufacturing spread, temperature, drifts with ageing at the stress levels used

c. De-rating

d. The operating junction temperature of each semoconductor will be calculated for the maximum ambient temperature.

16.8.3 Rotary Stepping Switches

Rotary stepping switches are to be used extensively for control, selection and adjustment purposes in the multipurpose receiver. The rotary stepping switches are especially suited for the application since as many as 12 discrete positions may be obtained with a single solenoid. In the intended application the solenoid will be energized less than one per cent of the operating time.

The most probable mode of failure of the rotary switch contacts is a failure to close, since the rotary solenoid has sufficient torque to overcome almost any contact welding or jamming which may occur. Therefore, all rotary switch sections will be connected in redundant (parallel) configurations whenever packaging space permits.

The proposed rotary stepping switches are presently being used successfully in missile programs which have more severe environmental requirements than that expected for the multipurpose receiver.

16.9 FAILURE RATE ANALYSIS DATA

Failure rate analysis data that was summarized in previous sections is presented in detail in Tables 16-3 through 16-27.

TABLE 16-3

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 1

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 1				
AM single conversion-no feedback system-no monopulse receiver.				
<u>Receiver</u>:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
5 Stage I-F Amplifier Ckt.	3	-	0.560	1.680
AM Detector Ckt.	1	-	0.086	0.086
Bandwidth Control Ckt.	1	-	0.300	0.300
Emitter Follower Ckt.	4	-	0.077	0.308
Amp. and EF Ckt.	1	-	0.168	0.168
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
RRC Ckt.	1	-	0.081	0.081
Threshold Amp. Ckt.	1	-	0.230	0.230
<u>RF Tuning Heads and Switching</u>:				
RF Tuning Heads	1	-	0.497	0.378
Preselector Switching	1	-	0.378	0.378
<u>Remote Controls and Switching</u>:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065
<u>Freq. Synthesizer Remote Controls</u>:	1	-	7.248	7.248
<u>Internal Local Oscillator</u>:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	1	-	0.077	0.077

TABLE 16-4

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 2

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
ANALYSIS NO. 2				
AM single conversion with external local oscillator-no monopulse receiver-no feedback system.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
5 Stage I-F Amplifier Ckt.	3	-	0.560	1.680
AM Detector Ckt.	1	-	0.086	0.086
Bandwidth Control Ckt.	1	-	0.300	0.300
Emitter Follower Ckt.	4	-	0.077	0.308
Amp. and EF Ckt.	1	-	0.168	0.168
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
RRC Ckt.	1	-	0.081	0.081
Threshold Amp. Ckt.	1	-	0.230	0.230
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065

TABLE 16-5

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 3

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
ANALYSIS NO. 3				
FM single conversion-no feedback system-no monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt.	1	-	0.376	0.376
5 Stage I-F Amplifier Ckt.	3	-	0.560	1.680
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	1	-	0.300	0.300
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	1	-	0.168	0.168
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
RRC Ckt.	1	-	0.081	0.081
Threshold Amp. Ckt.	1	-	0.230	0.230
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	1	-	0.077	0.077

TABLE 16-6

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 4

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PARTS	TOTAL
ANALYSIS NO. 4				
FM single conversion with external local oscillator-no monopulse receiver-no feedback system.				
<u>Receiver</u>:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt.	1	-	0.376	0.376
5 Stage I-F Amplifier Ckt.	3	-	0.560	1.680
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	1	-	0.300	0.300
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	1	-	0.168	0.168
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
RRC Ckt.	1	-	0.081	0.081
Threshold Amp. Ckt.	1	-	0.230	0.230
<u>RF Tuning Heads and Switching</u>:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
<u>Remote Controls and Switching</u>:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065

TABLE 16-7

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 5

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 5				
FM single conversion frequency lock first mexer-no monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt	1	-	0.376	0.376
5 Stage I-F Amplifier Ckt.	3	-	0.560	1.680
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	1	-	0.300	0.300
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	1	-	0.168	0.168
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
RRC Ckt.	1	-	0.081	0.081
Threshold Amp. Ckt.	1	-	0.230	0.230
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
Feedback Amp. Ckt.	1	-	0.276	0.276
2 Stage Tuned Amp. Ckt.	1	-	0.232	0.232
Transistor Mixer Ckt.	1	-	0.124	0.124
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching				
HG Band Switching Controls	1	-	1.368	1.368
Girst Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065
Frequency Feedback Switch	1	-	0.030	0.030
First Mixer Mode Switch	1	-	0.082	0.082
Frequency Lock Bandwidth Controls	1	-	0.591	0.591
Frequency Lock Resistor Controls	1	-	0.230	0.230
VCO Manual Tuning	1	-	1.636	1.636
External VCO Switch	1	-	0.001	0.001

TABLE 16-7 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	1	-	0.077	0.077

TABLE 16-8

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 6

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PARTS	TOTAL
ANALYSIS NO. 6				
AM double conversion-no feedback system-no monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.103	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591

TABLE 16-8 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	3	-	0.077	0.221
Transistor Mixer Ckt.	1	-	0.124	0.124

TABLE 16-9

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 7

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
ANALYSIS NO. 7				
AM double conversion with monopulse receiver-no feedback system.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-10

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 8

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 8				
AM double conversion with external local oscillator-no feedback system-no monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591

TABLE 16-11

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 9

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 9				
AM double conversion with external local oscillator and monopulse receiver-no feedback system				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591

TABLE 16-11 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	3	-	0.077	0.221
Transistor Mixer Ckt.	1	-	0.124	0.124
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-12

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 10

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 10				
FM double conversion-no feedback system-no monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filer Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591

TABLE 16-12 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	3	-	0.077	0.221
Transistor Mixer Ckt.	1	-	0.124	0.124

TABLE 16-13

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 11

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25oC IN %/1000 HRS. PER PART	TOTAL
ANALYSIS NO. 11				
FM double conversion with external local oscillator and monopulse receiver-no feedback system.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope and Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591

TABLE 16-13 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	3	-	0.077	0.221
Transistor Mixer Ckt.	1	-	0.124	0.124
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-14

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 12

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 12				
FM double conversion with external local oscillator-no feedback system-no monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Rmote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591

TABLE 16-15

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 13

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 13				
FM double conversion with monopulse receiver-no feedback system.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Power Amplifier	1	-	0.348	0.348
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amp. Ckt.	3	-	0.202	0.606
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
AGC Mode Switch	1	-	0.135	0.135
Local Oscillator Switch	1	-	0.002	0.002
Gain Controls	2	-	0.065	0.130
Second Mixer Frequency Switch	1	-	0.082	0.082
AGC Bandwidth Controls	1	-	0.591	0.591

TABLE 16-15 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit;				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-16

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 14

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 14				
FM double conversion frequency lock second mixer with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	6	-	0.077	0.462
Amp. and EF Ckt.	2	-	0.168	0.336
Dist. Amp. Ckt.	1	-	0.366	0.366
Voltage Control Amp. Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
Feedback Amp. Ckt.	1	-	0.276	0.276
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	1	-	0.108	0.108
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065
Freq. Lock Bandwidth Controls	1	-	0.591	0.591

TABLE 16-16 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Remote Controls and Switching (Cont'd.)				
VCO Manual Tuning	1	-	1.636	1.636
AGC Mode Switch	1	-	0.135	0.135
AGC Bandwidth Controls	1	-	0.591	0.591
Second Mixer Feedback Mode Switch	1	-	0.135	0.135
Second Mixer Freq. Switch	2	-	0.082	0.164
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	1	-	0.077	0.077

TABLE 16-17

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 15

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
ANALYSIS NO. 15				
FM double conversion frequency lock second mixer with external local oscillator and monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	6	-	0.077	0.462
Amp. and EF Ckt.	2	-	0.168	0.336
Dist. Amp. Ckt.	1	-	0.366	0.366
Voltage Control Amplieifer Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
Feedback Amp. Ckt.	1	-	0.276	0.276
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	1	-	0.108	0.108
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065
Frequency Lock Bandwidth Controls	1	-	0.591	0.591

TABLE 16-17 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
VCO Manual Tuning	1	-	1.636	1.636
AGC Mode Switch	1	-	0.135	0.135
AGC Bandwidth Controls	1	-	0.591	0.591
Second Mixer Feedback Mode Switch	1	-	0.135	0.135
Second Mixer Freq. Switch	2	-	0.082	0.164
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-18

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 16

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 16				
FM double conversion frequency lock first mixer with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
AM Detector Ckt.	1	-	0.086	0.086
Frequency Discriminator Ckt.	1	-	0.256	0.256
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	5	-	0.077	0.385
Amp. and EF Ckt.	2	-	0.168	0.336
Dist. Amp. Ckt.	1	-	0.366	0.366
Voltage Control Amp. Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
Feedback Amp. Ckt.	1	-	0.276	0.276
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	2	-	0.124	0.248
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
Power Amplifier	1	-	0.348	0.348
2 Stage Tuned Amp. Ckt.	1	-	0.232	0.232
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Remote Controls & Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Control Switch	1	-	0.082	0.082
Gain Controls	1	-	0.065	0.065

TABLE 16-18 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS. PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
Frequency Feedback Switch	1	-	0.030	0.030
Freq. Lock Bandwidth Controls	1	-	0.591	0.591
VCO Manual Tuning	1	-	1.636	1.636
AGC Mode Switch	1	-	0.135	0.135
AGC Bandwidth Controls	1	-	0.591	0.591
Second Mixer Feedback Mode Switch	1	-	0.135	0.135
Second Mixer Frequency Switch	1	-	0.082	0.082
External VCO Switch	1	-	0.001	0.001
Frequency Lock Resistor Controls	1	-	0.230	0.230
First Mixer Mode Switch	1	-	0.082	0.082
Local Oscillator Switch	1	-	0.002	0.002
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385
Internal Local Oscillator:				
STALO Power Supply	1	-	2.260	2.260
STALO Frequency Generator	1	-	2.682	2.682
Frequency Synthesizer	1	-	16.789	16.789
Emitter Follower Ckt.	3	-	0.077	0.221
Transistor Mixer Ckt.	1	-	0.124	0.124

TABLE 16-19

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 17

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 17				
Phase lock FM/PM out, double conversion phase lock first mixer-manual acquisition mode with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. and Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	7	-	0.077	0.539
Amp. and EF Ckt.	2	-	0.168	0.336
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation Amp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	2	-	0.124	0.248
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
Power Amplifier	1	-	0.348	0.348
2 Stage Tuned Amp. Ckt.	3	-	0.232	0.696
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130
AGC Control Switch	1	-	0.082	0.082

TABLE 16-19 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS. PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
VCO Manual Tuning Controls	1	-	1.636	1.636
Phase Lock Bandwidth Controls	1	-	1.061	1.061
First Mixer Mode Switch	1	-	0.082	0.082
External VCO Switch	1	-	0.001	0.001
Local Oscillator Switch	1	-	0.002	0.002
Phase Lock Resistor Controls	1	-	0.410	0.410
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	5	-	0.077	0.385
Transistor Mixer Ckt.	1	-	0.124	0.124
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-20

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 18

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS. PER PART	TOTAL
ANALYSIS NO. 18				
Phase lock FM/PM out, Double conversion phase lock first mixer-automatic acquisition mode with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	7	-	0.077	0.539
Amp. and EF Ckt.	2	-	0.168	0.336
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amp. Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation Amp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	2	-	0.124	0.248
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
Power Amplifier	1	-	0.348	0.348
2 Stage Tuned Amp. Ckt.	3	-	0.232	0.696
Remote Controls & Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC Mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130
AGC Control Switch	1	-	0.082	0.082

TABLE 16-20 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
VCO Manual Tuning Controls	1	-	1.636	1.636
Phase Lock Bandwidth Controls	1	-	1.061	1.061
First Mixer Mode Switch	1	-	0.082	0.082
External VCO Switch	1	-	0.001	0.001
Local Oscillator Switch	1	-	0.002	0.002
Phase Lock Resistor Controls	1	-	0.410	0.410
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	5	-	0.077	0.385
Transistor Mixer Ckt.	1	-	0.124	0.124
RF Tuning Heads & Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remotoe Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385
Automatic Acquisition Control:				
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Schmitt Trigger Ckt.	1	-	0.217	0.217
Sweep Oscillator Ckt.	1	-	0.653	0.653
Gate & Level Hold Ckt.	1	-	0.241	0.241
Relay Control Ckt.	1	-	0.075	0.075
Switch Hold Ckt.	1	-	0.165	0.165
Gain Controls	1	-	0.065	0.065
Noise Bandwidth Controls	1	-	0.121	0.121
Sweep Oscillator Controls	1	-	0.300	0.300
External VCO Switch	1	-	0.001	0.001
Emitter Follower Ckt.	1	-	0.077	0.077

TABLE 16-21

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 19

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 19				
Phase lock AM out, double conversion phase lock first mixer-manual acquisition mode with monopulse receiver.				
<u>Receiver</u>:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower CKt.	10	-	0.077	0.770
Amp. and EF Ckt.	1	-	0.168	0.168
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amp. Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation Amp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	2	-	0.124	0.248
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
Power Amplifier	1	-	0.348	0.348
2 Stage Audio Amp. Ckt.	1	-	0.184	0.184
2 Stage Tuned Amp. Ckt.	3	-	0.232	0.696
<u>Remote Controls & Switching</u>:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC Mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130

TABLE 16-21 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
AGC Control Switch	1	-	0.082	0.082
VCO Manual Tuning Controls	1	-	1.636	1.636
Phase Lock Bandwidth Controls	1	-	1.061	1.061
First Mixer Mode Switch	1	-	0.082	0.082
External VCO Switch	1	-	0.001	0.001
Local Oscillator Switch	1	-	0.002	0.002
Phase Lock Resistor Controls	1	-	0.410	0.410
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	5	-	0.077	0.385
Transistor Mixer Ckt.	1	-	0.124	0.124
RF Tuning Heads & Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-22

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 20

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 20				
Phase lock AM out, double conversion phase lock first mixer-automatic acquisition mode with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	10	-	0.077	0.770
Amp. and EF Ckt.	1	-	0.168	0.168
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amp. Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation Amp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	2	-	0.124	0.248
HG X4 Ckt.	2	-	0.108	0.216
RRC Ckt.	1	-	0.081	0.081
Slope & Delay Control Ckt.	1	-	0.770	0.770
Power Amplifier	1	-	0.348	0.348
2 Stage Audio Amp. Ckt.	1	-	0.184	0.184
2 Stage Tuned Amp. Ckt.	3	-	0.232	0.696
Remote Controls & Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC Mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130

TABLE 16-22 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
AGC Control Switch	1	-	0.082	0.082
VCO Manual Tuning Controls	1	-	1.636	1.636
Phase Lock Bandwidth Controls	1	-	1.061	1.061
First Mixer Mode Switch	1	-	0.082	0.082
External VCO Switch	1	-	0.001	0.001
Local Oscillator Switch	1	-	0.002	0.002
Phase Lock Resistor Controls	1	-	0.410	0.410
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	5	-	0.077	0.385
Transistor Mixer Ckt.	1	-	0.124	0.124
RF Tuning Heads & Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385
Automatic Acqusition Control:				
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Schmitt Trigger Ckt.	1	-	0.217	0.217
Sweep Oscillator Ckt.	1	-	0.653	0.653
Gate & Level Hold Ckt.	1	-	0.241	0.241
Relay Control Ckt.	1	-	0.075	0.075
Switch Hold Ckt.	1	-	0.165	0.165
Gain Controls	1	-	0.065	0.065
Noise Bandwidth Controls	1	-	0.121	0.121
Sweep Oscillator Controls	1	-	0.300	0.300
External VCO Switch	1	-	0.001	0.001
Emitter Follower Ckt.	1	-	0.077	0.077

TABLE 16-23

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 21

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE IN 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 21				
Phase lock FM/PM out, double conversion phase lock second mixer-manual acquisition mode with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	10	-	0.077	0.770
Amp. and EF Ckt.	2	-	0.168	0.336
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation Amp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	1	-	0.108	0.108
RRC Ckt.	2	-	0.081	0.162
Slope & Delay Control Ckt.	1	-	0.770	0.770
AM Detector Ckt.	1	-	0.086	0.086
2 Stage Tuned Amp. Ckt.	2	-	0.232	0.464
Remote Controls & Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC Mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130
AGC Control Switch	1	-	0.082	0.082

TABLE 16-23 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
VCO Manual Tuning Controls	1	-	1.636	1.636
Phase Lock Bandwidth Controls	1	-	1.061	1.061
Second Mixer Frequency Switch	2	-	0.082	0.164
Second Mixer Feedback Mode Switch	1	-	0.135	0.135
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	3	-	0.077	0.231
RF Tuning Heads & Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-24

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 22

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 22				
Phase lock FM/PM out, double conversion phase lock second mixer-automatic acquisition mode with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	10	-	0.077	0.770
Amp. and EF Ckt.	2	-	0.168	0.336
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation Amp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	1	-	0.108	0.108
RRC Ckt.	2	-	0.081	0.162
Slope & Delay Control Ckt.	1	-	0.770	0.770
AM Detector Ckt.	1	-	0.086	0.086
2 Stage Tuned Amp. Ckt.	2	-	0.232	0.464
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC Mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130
AGC Control Switch	1	-	0.082	0.082
VCO Manual Tuning Controls	1	-	1.636	1.636

TABLE 16-24 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
Phase Lock Bandwidth Controls	1	-	1.061	1.061
Second Mixer Frequency Switch	2	-	0.082	0.164
Second Mixer Feedback Mode Switch	1	-	0.135	0.135
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	3	-	0.077	0.231
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385
Automatic Acquisition Control:				
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Schmitt Trigger Ckt.	1	-	0.217	0.217
Sweep Oscillator Ckt.	1	-	0.653	0.653
Gate & Level Hold Ckt.	1	-	0.241	0.241
Relay Control Ckt.	1	-	0.075	0.075
Switch Hold Ckt.	1	-	0.165	0.165
Gain Controls	1	-	0.065	0.065
Noise Bandwidth Controls	1	-	0.121	0.121
Sweep Oscillator Controls	1	-	0.300	0.300
External VCO Switch	1	-	0.001	0.001
Emitter Follower Ckt.	1	-	0.077	0.077

TABLE 16-25

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 23

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
ANALYSIS NO. 23				
Phase lock AM out, double conversion phase lock second mixer-manual acquisition mode with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	13	-	0.077	1.001
Amp. and EF Ckt.	1	-	0.168	0.168
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amp. Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation Amp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	1	-	0.108	0.108
RRC Ckt.	2	-	0.081	0.162
Slope & Delay Control Ckt.	1	-	0.770	0.770
AM Detector Ckt.	1	-	0.086	0.086
2 Stage Audio Amp. Ckt.	1	-	0.184	0.184
2 Stage Tuned Amp. Ckt.	2	-	0.232	0.464
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC Mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130

TABLE 16-25 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
Remote Controls & Switching (Cont'd.)				
AGC Control Switch	1	-	0.082	0.082
VCO Manual Tuning Controls	1	-	1.636	1.636
Phase Lock Bandwidth Controls	1	-	1.061	1.061
Second Mixer Frequency Switch	2	-	0.082	0.164
Second Mixer Feedback Mode Switch	1	-	0.135	0.135
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	3	-	0.077	0.231
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385

TABLE 16-26

FAILURE RATE ANALYSIS DATA
MULTIPURPOSE RECEIVER

ANALYSIS NO. 24

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS.	
			PER PART	TOTAL
ANALYSIS NO. 24				
Phase lock AM out, double conversion phase lock second mixer-automatic acquisition mode with monopulse receiver.				
Receiver:				
Harmonic Generators	1	-	0.908	0.908
Regulated Power Supply	1	-	0.826	0.826
Voltage Control BP Filter Ckt.	2	-	0.119	0.238
LP Filter Ckt.	1	-	0.014	0.014
3 Stage I-F Amp. & Limiter Ckt.	1	-	0.376	0.376
4 Stage I-F Amplifier Ckt.	2	-	0.448	0.896
5 Stage I-F Amplifier Ckt.	1	-	0.560	0.560
Phase Detector Ckt.	2	-	0.084	0.168
Bandwidth Control Ckt.	2	-	0.300	0.600
Emitter Follower Ckt.	13	-	0.077	1.001
Amp. and EF Ckt.	1	-	0.168	0.168
Dist. Amp. Ckt.	2	-	0.366	0.732
Voltage Control Amplifier Ckt.	3	-	0.202	0.606
Isol. Amp. and VCO Ckt.	1	-	0.316	0.316
DC Operation AMp. Ckt.	1	-	0.619	0.619
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Transistor Mixer Ckt.	1	-	0.124	0.124
HG X4 Ckt.	1	-	0.108	0.108
RRC Ckt.	2	-	0.081	0.162
Slope & Delay Control Ckt.	1	-	0.770	0.770
AM Detector Ckt.	1	-	0.086	0.086
2 Stage Audio Amp. Ckt.	1	-	0.184	0.184
2 Stage Tuned Amp. Ckt.	2	-	0.232	0.464
Remote Controls and Switching:				
HG Band Switching Controls	1	-	1.368	1.368
First Mixer Feedback Control	1	-	0.447	0.447
AGC Bandwidth Controls	1	-	0.121	0.121
AGC Mode Switch	1	-	0.135	0.135
Gain Controls	2	-	0.065	0.130

TABLE 16-26 (Continued)

COMPONENT	NO. OF PARTS	STRESS RATIO	FAILURE RATE AT 25°C IN %/1000 HRS. PER PART	TOTAL
Remote Controls and Switching (Cont'd.)				
AGC Control Switch	1	-	0.082	0.082
VCO Manual Tuning Controls	1	-	1.636	1.636
Phase Lock Bandwidth Controls	1	-	1.061	1.061
Second Mixer Frequency Switch	2	-	0.082	0.164
Second Mixer Feedback Mode Switch	1	-	0.135	0.135
Internal Local Oscillator:				
Frequency Synthesizer	1	-	16.789	16.789
STALO Power Supply	1	-	2.260	2.260
STALO Generator	1	-	2.682	2.682
Emitter Follower Ckt.	3	-	0.077	0.231
RF Tuning Heads and Switching:				
RF Tuning Heads	1	-	0.497	0.497
Preselector Switching	1	-	0.378	0.378
Freq. Synthesizer Remote Controls:	1	-	7.248	7.248
Monopulse Receiver Unit:				
Monopulse Receiver	2	-	4.598	9.196
Emitter Follower Ckt.	5	-	0.077	0.385
Automatic Acquisition Control:				
3 Stage Audio Amp. Ckt.	1	-	0.276	0.276
Schmitt Trigger Ckt.	1	-	0.217	0.217
Sweep Oscillator Ckt.	1	-	0.653	0.653
Gate & Level Hold Ckt.	1	-	0.241	0.241
Relay Control Ckt.	1	-	0.075	0.075
Switch Hold Ckt.	1	-	0.165	0.165
Gain Controls	1	-	0.065	0.065
Noise Bandwidth Controls	1	-	0.121	0.121
Sweep Oscillator Controls	1	-	0.300	0.300
External VCO Switch	1	-	0.001	0.001
Emitter Follower Ckt.	1	-	0.077	0.077

SECTION 17

MAINTAINABILITY

17.1 STATEMENT OF THE PROBLEM

The primary factor affecting the maintainability design of the multipurpose receiver is a mean-time-to-restore (MTR) goal of six minutes. Other maintainability criteria include the relative ease, economy, and accuracy with which the system can be kept in, or returned to, a specified operating condition. These objectives must be attained within a framework of other requirements and constraints, such as performance, reliability, cost, schedules, etc.

Three levels of maintainability, each of which have specific implications for design, are listed below:

1. On-Line (Operational) Maintainability: Equipment characteristics and associated procedures required to restore the system to an operating state. The measure of on-line maintainability is "restore time" which is the interval between system failure and restoration of the system to an operational status.

2. Off-Line (Bench or Repair Shop) Maintainability: Equipment characteristics and associated procedures required to return failed modules or repairable items to a working state so that they will be available for installation in the equipment. The measure of off-line maintainability is "repair time" which is the time required to return faulty items or modules to a useable condition.

3. Preventive Maintenance Design: Equipment characteristics and associated procedures required to examine the system for potential failures and to service the system on a scheduled basis. "Scheduled maintenance time" is the time measure of preventive maintenance design.

To adequately design equipment for maintainability, it is necessary to determine and examine the elements of maintenance time and the factors which affect these times. The former consist of fault detection, localization, isolation, correction, and correction verification operations. The factors which affect the time required to perform these operations include system design, hardware design, tools and test equipment, number, skill level, and training of maintenance personnel, technical manuals, and physical environment.

Because of the stringent requirement on the time to complete on-line maintenance, some relatively new and unique approaches to the maintenance problem are necessary. To this end, MIL-M-26512A "Maintainability Requirements for Weapon, Support, and Command and Control Systems, and Equipment," MIL STD 803, "Human Engineering Criteria for Aircraft, Missiles, Space Systems and Ground Support Equipment," and SSD-TDR-62-23 "A Maintainability Program for Aerospace Systems and Equipment," are used for guidance.

17.2 DISCUSSION OF THE PROBLEM

The two design parameters which determine the availability of the multipurpose receiver are reliability, expressed in terms of mean-time-between-failures (MTBF) and maintainability, which is quantitatively measured as mean-time-to-restore (MTR) or the interval of time between failure occurrence and correction verification at which time the system is considered ready for operation.

Reference to Figure 17-1, a graphic representation of the availability formula, $A = \frac{MTBF}{MTBF + MTR}$ shows that, for a given availability, an infinite number of combinations of MTR and MTBF are possible. For the multipurpose receiver, a reliability design goal of 1,000 hours for the MTBF has been established, resulting in an MTR of six minutes.

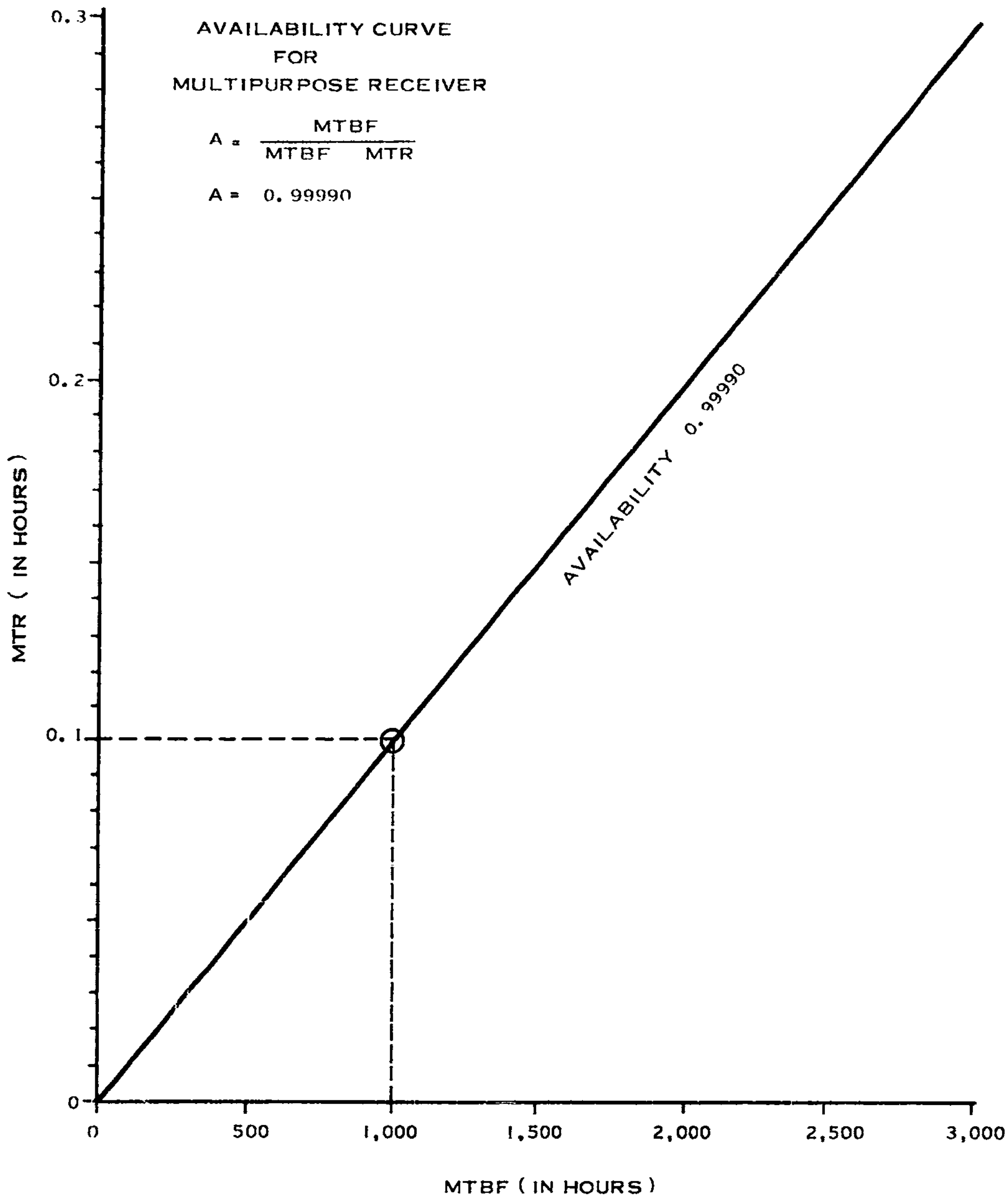


Fig. 17-1 Availability Curve

It is important to note the effect of several different values of MTBF on MTR for the given 0.9999 availability figure. For example, if the MTBF is 500 hours, the MTR requirement becomes 3 minutes, whereas a reliability of 2,000 hours permits a longer MTR, namely 12 minutes.

Since MTR is a statistical time representing the average or mean "on-line corrective maintenance time, maintenance times for specific malfunctions will be greater than the mean value in some instances and less in others. Therefore, in many cases it is necessary to design for something less than six minutes to compensate for those malfunctions for which longer maintenance times are anticipated.

To achieve a short MTR, emphasis will be placed upon modularization or the unitization of functions and hardware. This approach enables a technician to limit the extent of his on-line maintenance actions to the isolation of malfunctions to a relatively large group of parts. Implicit in this approach, however, is a requirement for the availability or replacement modules or chassis.

It is assumed that the time necessary to detect, isolate, and correct plug-in or modular types of malfunctions will be less than for non-plug-in items. Figure 17-2 illustrates the MTR requirements for non-plug-in items necessary to achieve an overall six-minute MTR goal for various values of MTR for plug-in units. Four curves are shown for a number of plug-in module MTR times. The percent of total failure rate for non-plug-in units appears on the ordinate of the figure and the corresponding MTR requirement for these non-plug-in items appears on the abscissa. It can be seen that as the non-plug-in failure rate increases relative to the total failure rate, the plug-in MTR must be reduced (assuming a constant non-plug-in MTR) in order to meet the overall six-minute MTR goal. Also from the illustration, it should be noted that when the non-plug-in percentage of the total failure rate is large, reduction of the MTR for plug-in units does not appreciably reduce the MTR requirement for non-plu-in units.

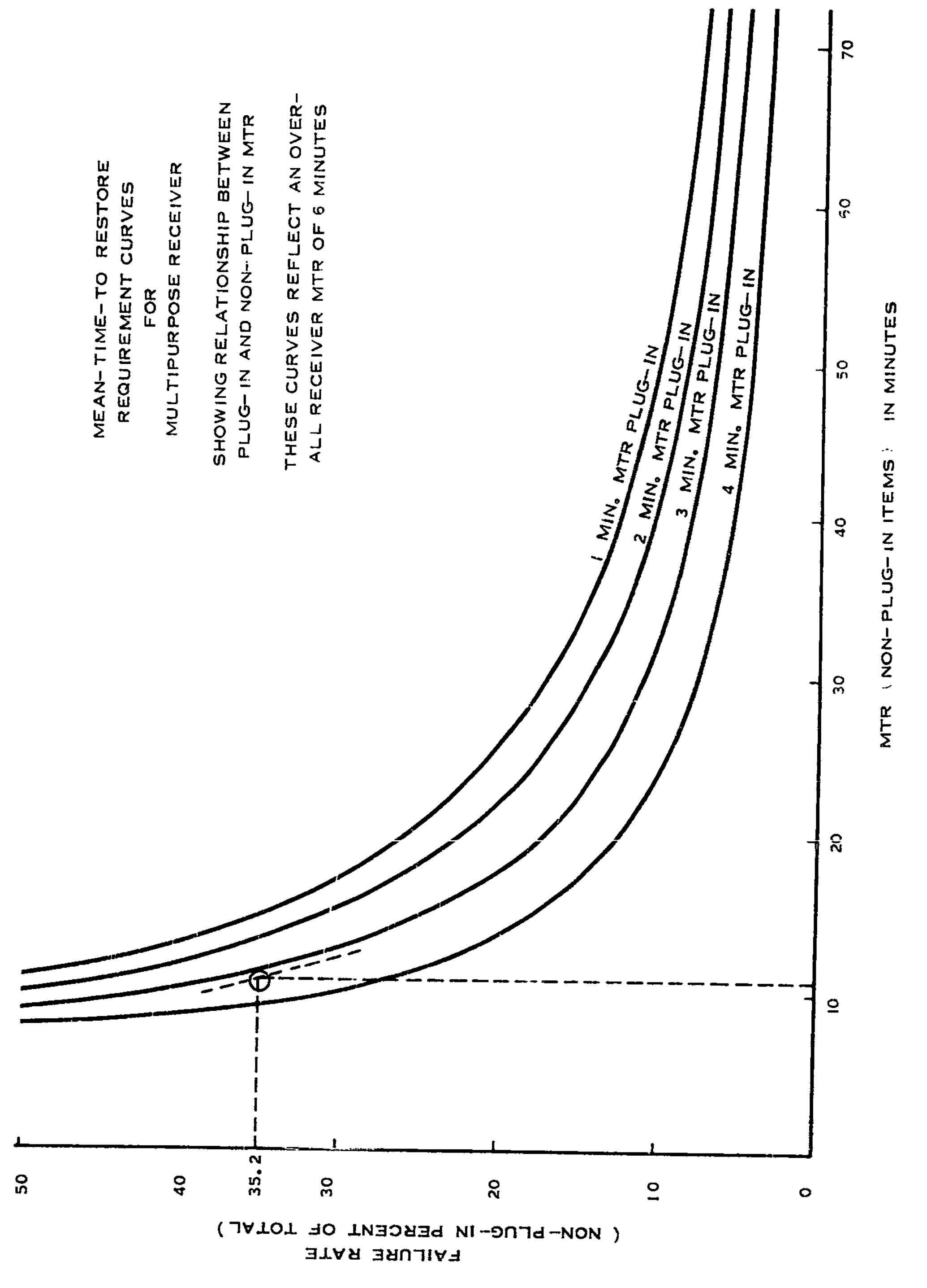


Fig 17-2 Mean - Time - To - Restore Requirement Curves

However, when the ratio of non-plug-in failures to total failures is small, a small improvement in the modular MTR permits a relatively large increase in allowable non-plug-in MTR and still preserve the overall six-minute MTR.

In general, then, the MTR goal for modular units will depend upon the ratio of non-modular failure rates to the total failure rate. Also, the particular modular MTR goal will have to be less than six minutes unless non-modular failures can also be detected, isolated, and corrected, on the average, in six minutes.

A maintenance time analysis indicates that the present design configuration of the multipurpose receiver has a predicted MTR of 13.5 minutes. This overall MTR is obtained from a predicted MTR of 3.4 minutes for plug-in units and 32 minutes for non-plug-in units where the failure rate contribution of non-plug-in malfunctions is 33.2 percent of the total failures; (see Fig. 3, Multipurpose Receiver Maintenance Time Analysis). The predicted maintenance times reflect the excessive time required to restore non-plug-in types of failures which necessitate the use of additional tools, test equipment, and more extensive diagnosis during the troubleshooting process. Estimated times shown in Table 17-1 were based upon the following conditions and assumptions:

a. Maintenance personnel will posses above average skills in fault isolation, in removing and replacing non-plug-in parts, and will have received specialized maintenance training which emphasizes signal flow paths, troubleshooting, and relative failure probabilities.

b. Test equipment and troubleshooting aids, such as interconnecting cables and adapters, are available in the immediate vicinity of the multipurpose receiver.

TABLE 17-1

MULTIPURPOSE RECEIVER MAINTENANCE TIME ANALYSIS

	Isolation	Remove & Replace	Calib. & Verification	Total Time (t) (in min)	(λ) Failure Rate (in %/K hrs.)	λt	MTR
Receiver							
Modules	2.0	1.5	0.2	3.7	18.947	70.1	
Switches & Controls	30.0	20.0	1.0	51.0	5.477	279.3	
Connectors	15.0	9.0	1.0	25.0	1.650	41.2	
Coax. Connectors	15.0	1.0	1.0	17.0	2.750	46.8	
			TOTAL	96.7	28.824	437.4	15.2
Synthesizer							
Modules	0.5	1.5	0.2	2.2	16.847	37.1	
Switches & Controls	15.0	16.0	1.0	32.0	7.248	231.9	
Connectors	12.0	11.0	1.0	24.0	0.750	18.0	
Coax. Connectors	8.0	1.0	1.0	10.0	0.800	8.0	
			TOTAL	68.2	25.645	295.0	11.5
Harmonic Generator							
Modules	1.5	1.0	0.2	2.7	.908	2.4	
Switches	15.0	14.0	1.0	30.0	0.040	1.2	
Connectors	10.0	9.0	1.0	20.0	0.060	1.2	
Coax. Connectors	10.0	1.0	1.0	12.0	0.440	5.3	
			TOTAL	64.7	1.448	10.1	7.0
STALO a.	20.0	8.0	9.0	37.0	2.682	99.2	37.0
b.	3.0	4.0	9.0	16.0	2.682	42.9	16.0
STALO P.S. a.	15.0	11.0	2.0	28.0	2.660	74.5	28.0
b.	2.0	4.0	2.0	8.0	2.660	21.3	8.0
Monopulse Receiver							
Modules	2.0	1.5	0.5	4.0	9.581	38.3	
Connectors	15.0	10.0	1.0	26.0	0.600	15.6	
Coax. Connectors	12.0	1.0	1.0	14.0	0.800	11.2	
Controls	11.0	7.0	1.0	19.0	0.270	5.1	
			TOTAL	63.0	11.251	70.2	6.2
Regulated P.S.							
Modules	5.0	1.0	1.0	7.0	2.776	19.4	
Connectors	18.0	12.0	1.0	31.0	0.468	14.5	
			TOTAL	38.0	3.244	33.9	10.5
STALO & STALO P.S. a. Repairs made within b. Entire unit replaced					OVERALL MTR		a. 13.5 b. 12.0

c. Up-to-date drawings, schematics, and analytically developed and validated trouble analysis procedures and charts are provided and available.

d. Spare modules and piece parts are stored in the immediate area for easy access.

e. Necessary tools and additional maintenance aids to permit examination of input and output signals of each module are provided to facilitate repair and non-modular fault isolation, respectively.

The predicted MTR of 13.5 minutes decreases the system availability from 0.99990 to 0.99975, assuming a MTBF of 1000 hours. An availability of 0.99990 can be achieved through either an increase in MTBF or a reduction in MTR. The former approach requires a reliability improvement of 250 hours in MTBF, whereas the latter solution would necessitate a decrease in the overall MTR to six minutes. This maintainability improvement could probably be most easily obtained through a reduction in the non-modular MTR from 32 to 11 minutes, as shown in Fig. 17-2.

17.3 APPROACH TO MAINTAINABILITY DESIGN OF THE MULTIPURPOSE RECEIVER

Two distinct equipment design characteristics affect the eventual maintainability of the equipment: i.e., the system maintainability design philosophy or maintainability hardware approach and the detailed maintainability design attributes. The former is concerned with the degree of maintenance automaticity built into the equipment while the latter is a function of the extent of adherence to detailed maintainability design principles and practices. Both of these design characteristics must also consider other factors which have a bearing on the relative rapidity, ease, accuracy and economy with which maintenance operations are performed. These factors include skill level and training of maintenance personnel, tools and test equipment, technical manuals and the environment in which maintenance will be performed.

17.3.1 The Maintainability Hardware Approach

The maintainability hardware approach selected for the multipurpose receiver to achieve a six-minute MTR goal consists of semi-automatic fault detection and isolation schemes. Modular faults are detected on indicators which have been selected and grouped on the basis of electronic and human engineering principles and requirements. Fault isolation is accomplished by semi-automatic identification of defective modules by means of a series of lights which display the status of critical receiver functions. The technician isolates the defective module in the receiver and synthesizer by interpreting the malfunction symptom patterns of these indicators. Fault correction, however, is accomplished manually by removal and replacement of the faulty module.

For this scheme to be effective, the failure-reporting system must be designed to be highly reliable. Also, to minimize operator error in maintenance as well as operation, automatic control features are provided. This approach simplifies operation and maintenance, and provides the required flexibility of adapting to changes in operating requirements.

17.4 DETAILED MAINTAINABILITY DESIGN ATTRIBUTES

To complement the maintainability hardware approach, design emphasis is given to features which enhance maintenance accomplishment. Failure rate data is used to determine areas of maintainability design emphasis. In addition to extensive modularization, attention is given to the following:

17.4.1 Accessibility

The time required to accomplish corrective maintenance subtasks is increased by the lack of accessibility to test points, adjustments, modules and individual parts. Specific accessibility features incorporated in the design of the multi-purpose receiver include but are not limited to:

a. Optimal location, arrangement (orientation) and grouping of items which must be observed, manipulated, removed and replaced.

b. Incorporation of cable retractors to permit chassis to be easily retracted.

c. Minimization and standarization of fasteners. Captive, quick release fasteners are used wherever practicable.

17.4.2 Connection and Assembly

Since fault detection and isolation are accomplished semi-automatically, the maintenance subtask which may contribute most to total maintenance time is the removal and replacement of defective items. In order to minimize the time necessary to perform this activity, the multipurpose reveiver uses plug-in components wherever necessary and practicable.

The correction of piece-part malfunctions becomes especially time-consuming when parts must be removed and replaced by unsoldering and resoldering. Accordingly, steeping switches which contain a large number of connections are provided with plug-in connectors. Wherever reliability/maintainability tradeoff studies dictate the impracticability of using connectors, terminal boards will be provided and connection facilitated through the use of easily removed cable and harness terminations such as spade lugs. To facilitate identification and replacement of blown fuses, they will be of the blowout-indicating type, located and mounted for easy removal and replacement. Spare

fuses will also be provided adjacent to the functional fuses and clearly identified.

To permit expeditious replacement of defective items, they will, wherever required, be identified and coded both functionally and according to location. Items included are modules, cables, connectors, harnesses, resistors, capacitors, etc.

The following order of priority is given to tool requirements for removal and replacement of defective items as well as for performing alignment, adjustment, and calibration.

1. Without tools where possible
2. With the minimum number of common and/or Air Force standard tools
3. With special tools.

In the selection of tools and equipment design characteristics for simplifying removal and replacement and alignment and adjustment, personnel and equipment damage aspects of equipment design will be considered. Items will be located such that required maintenance activities will not reduce the reliability of the equipment or expose the technician to safety hazards. Particular attention will be given to the following:

a. Reducing the proximity to high voltages
b. Avoiding sharp corners and protrusions
c. Providing tool and assembly guides wherever necessary.

17.5 OTHER CONSIDERATIONS

17.5.1 Logistics Philosophy

To assure rapid replacement of defective item, these items must be provided as spares and physically located in the immediate area of

the prime equipment. The spares should also be catalogues in a manner which would permit the technician to rapidly locate them. Time measurements which have been made by the Maintainability Assurance Section at the North Pacific Tracking Station indicate that from one to two minutes are required to locate spare chassis when they are not well catalogued, even though they are located in the working area. With a well developed method for rapid location of spares, the time could have been reduced to from one-half to one minute.

Although assurance of an adequate supply of modules and spare parts is considered the responsibility of Logistics, a reduction in the number of different types of parts, and items during equipment design whithin and between a particular class of equipment (rf, digital, etc.) can significantly reduce maintenance costs which accure over the lifetime of this equipment.

17.5.2 Manual Fault Isolation

Detailed maintainability design characteristics become increasingly improtant when isolation of equipment malfunctions must be accomplished manually, i.e., when the semi-automatic mode fails, cannot be used, or does not apply. In addition to incorporating design attributes previously mentioned, test points will be identified and coded and compatibility between test equipment probs and test points will be assured.

17.5.3 Off-Line and Preventive Maintenance Design

Two additional types of equipment maintenance are off-line and preventive maintenance.

Off-Line Maintenance. Off-Line maintenance refers to the maintenance that is performed on subassemblies, modules, etc., which have been removed from the operational setting. The requirement for off-line maintenance is that the repair manpower required for a given period of time be less than or equal to the available repair man hours

to prevent system unavailability due to spares shortage. Other constraints such as time, and must also be satisfied. The equipment to be repaired is determined in accordance with the accepted philosophy concerned with disposition of module failures. Three possible approaches are listed below:

1. Field Repair -- The failed unit is repaired at the station if this can be shown to be the most economical approach and if other major constraints are satisfied.

2. Depot Repair -- The failed unit may be returned to a depot for repair if, in general, it can be shown that the minimum cost of repairing the unit in the field greatly exceeds the cost of rotating the unit and the cost of repair at the depot or that the necessary test equipment is only available at the depot.

3. Discard -- The failed unit may be discarded if, in general, it can be shown that the minimum cost of repairing the unit greatly exceeds the cost of the unit and cost of logistics.

Preventive Maintenance. Preventive maintenance design considers those equipment features which facilitate servicing and inspecting the system to identify and prevent failures before they occur or develop into major defects. Specific to the design of the multipurpose receiver are the specification of preventive maintenance procedures and schedules and the provision of necessary service points. The selection, design and identification of these points will adhere to good maintainability design practices.

17.5.4 Maintenance Procedures and Training

A major time-consuming task of maintenance personnel consists of referring to reference material. This is particularly true during

trouble shooting, and especially when this activity must be performed manually. Since fault diagnosis or failure isolation appears to take the most corrective maintenance time, careful attention will be given to the methods of optimally presenting maintenance instructions, procedures and information. Accordingly, various methods of presenting the required information will be carefully examined and evaluated for both the manual and semi-automatic modes. Realistic maintenance procedures will be prepared during equipment design so that they will be available to the technician when the equipment is delivered since nearly designed or unavailable procedures can off-set the benefits of otherwise good equipment maintainability design.

Maintenance instructions will be written so that they will be easily understood and the format will be designed to allow rapid location of material by means of simple cross-referencing methods, extensive use of charts, tables, checklists, and validated step by step procedures. To the extent possible, and prior to the availability of multipurpose receiver hardware, the Human Factors and Operations Analysis Department's Maintainability Simulator will be used to develop this information. The availability of optimum sequences in terms of flow charts or step by step procedures for isolating each module will permit preliminary estimation of on-line corrective maintenance times.

Maintenance procedures are required for organizational, field, and depot levels of maintenance. These procedures should be included in individual manuals or sections of the manuals to simplify accomplishment of inspection, checking, trouble shooting, adjusting, repairing, and servicing at each of these levels. For example, on-line maintenance will consist mainly of isolating modular malfunctions. Information provided to the on-line technician should be limited to what he needs to know to perform this function at the organizational level.

A technique which may be employed in the design of trouble shooting procedures for on-line maintenance of the multipurpose receiver consists of the use of correspondence charts, matrices, and tables which associate malfunction symptom patterns on the fault reporting indicator lights with the defective modules.

To assure efficient utilization of the foregoing instructions and reference material, specialized training of technicians will be required.

It should be noted that the preceding information supplements data normally contained in technical manuals such as data flow, schematic and interconnection diagrams, wiring and parts lists, and theory of operation.

17.6 MAINTAINABILITY PLAN

17.6.1 Analysis

Maintainability analysis consists of an examination of maintenance factors and the system requirements which tend to fix or constrain them. The result of the analysis is the establishment of the maintainability hardware approach or equipment design techniques and assoicated procedures through which the time goals can be realized.

For the multipurpose receiver, a semi-automatic maintainability hardware approach has been selected to meet the six minute mean-time-to-restore goal. The three major maintainability requirements established are methods for:

1. Detection of the presence of a fault
2. Isolation of faults to a replaceable unit
3. Restoration of the equipment to satisfactory operation after the fault has been isolated.

<u>Detection</u>. Malfunctions will cause an abnormal pattern to be displayed on indicators which monitor critical receiver functions. These indicators will show a constant and easily recognized pattern when the receiver is operating satisfactorily.

<u>Isolation.</u> Semi-automatic fault location to a defective module is accomplished by comparison of malfunction indicator light patterns to symptom pattern/defective module matrices, or charts.

<u>Correction.</u> Correction is accomplished manually by the replacement of defective modules with spare units.

17.6.2 <u>Assurance</u>

The assurance portion of the maintainability plan consists of a systematic method whereby the maintainability requirements are effectively and economically achieved in equipment design. It is applicable to both Philco and vendor produced equipment throughout design, development and production. Maintainability assurance consists of:

a. Familiarization of equipment designers with maintainability design concepts and principles through participation in the Philco Maintainability Training Course

b. Use of "Maintainability Design Guides"

c. Utilization of Maintainability Group consultation services

d. Inclusion of maintainability requirements in equipment specifications

e. Maintainability design reviews to assure that equipment design is such that maintainability objectives will be met.

Relative to (e) above, since the progress of the development process is characterized by increasing ability to evaluate maintainability and decreasing freedom to improve it, emphasis in the review program is placed in the early design stages. Qualitative maintainability design checklists will be used to determine the degree of adherence to maintainability design principles.

17.6.3 <u>Evaluation</u>

The purpose of the evaluation phase of the maintainability plan is to quantitatively determine the degree of achievement of maintainability objectives and to provide data on which to base improvements in design.

Quantitative maintainability evaluation is accomplished by the insertion of simulated faults selected on the basis of failure rates and estimated maintenance times. The time to complete the maintenance tasks of detection, isolation, and correction will be measured and the data reviewed and evaluated.

The evaluation will be carried out under conditions which simulate the anticipated operational environment wherever possible. Maintenance personnel should be of a skill level equivalent to that required to standard maintenance positions. (Also standard Maintenance procedures, and reference material specified for use in the operational facility will be employed.)

The evaluation effort will be accomplished during the following two phases of the multipurpose receiver program:

<u>Design and Development Phase</u>. Evaluation is performed to verify mean-time-to-restore estimates and to identify any design inadequacies early in the development cycle when they can be readily

and economically corrected. To obtain a gross estimate of MTR in the early phases of design, the multipurpose receiver block diagram will be simulated on the maintainability simulator and the time required to perform representative maintenance tasks measured if feasible

Installation Phase. Evaluation will be made during this phase to demonstrate degree of achievement of amintainability objectives in the operational setting.

SECTION 18

SUMMARY OF RECEIVER OPERATION

18.1 INTRODUCTION

The receiver system operation can be categorized into groupings as follows:

a. Basic receiver and r-f heads
b. Frequency synthesizer and harmonic generator
c. Failure reporting and isolation system
d. Remote control
e. Monopulse receiver and r-f heads

All of the above groupings are included within the multipurpose receiver system and are available within a single 6-foot, standard 19-inch rack.

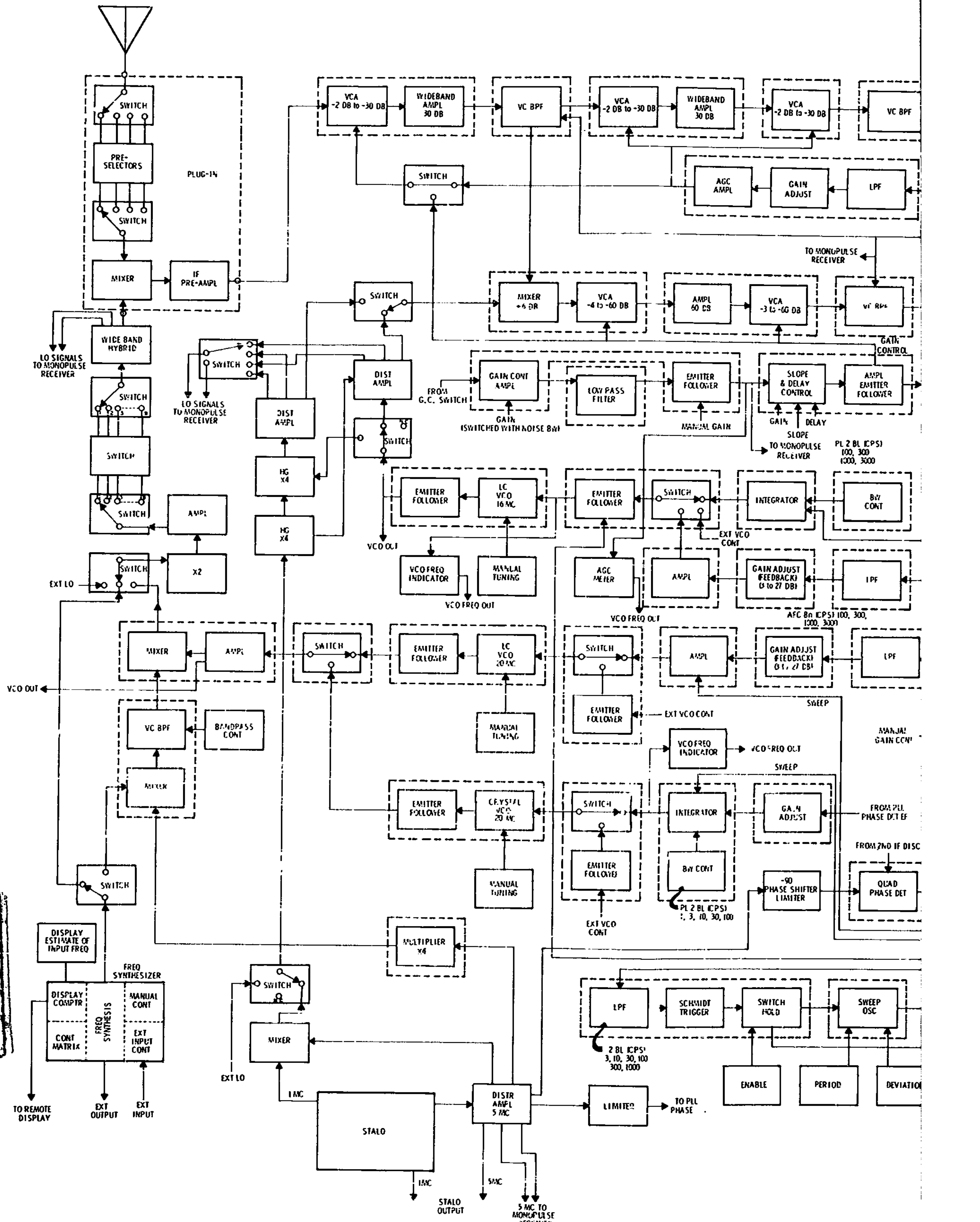
The entire receiver functional block diagram is shown in Fig. 18-1. The functional blocks are divided into modules for the basic receiver. Figure 18-2 is the functional block diagram of the monopulse receiver required for the two error channels

18.2 BASIC RECEIVER AND R-F HEADS

The basic receiver offers several alternate functions that include standard AM and FM, phase lock and FMFB (frequency lock). These functions along with their AGC and acquisition sweep circuits are mounted on a single chassis drawer.

Each r-f head with selected preselectors will cover an octave frequency band. They include a mixer and I-F preamplifier. Three of these can be mounted in a single chassis drawer. To cover the frequency range 100 mc to 10 Gc, six r-f heads and two chassis drawers are needed. Of course, these r-f heads can be mounted in the antenna reflector.

1


SWITCH
PRE-SELECTORS
PLUG-IN
MIXER
IF PRE-AMPL
WIDE BAND HYBRID
LO SIGNALS TO MONOPULSE RECEIVER
AMPL
X2
EXT LO
VCO OUT
VC BPF
BANDPASS CONT
DISPLAY ESTIMATE OF INPUT FREQ
FREQ SYNTHESIZER
DISPLAY COMPTR
FREQ SYNTHESIS
MANUAL CONT
CONT MATRIX
EXT INPUT CONT
TO REMOTE DISPLAY
EXT OUTPUT
EXT INPUT
VCA -2 DB to -30 DB
WIDEBAND AMPL 30 DB
VC BPF
AGC AMPL
GAIN ADJUST
LPF
TO MONOPULSE RECEIVER
MIXER +6 DB
VCA -4 to -60 DB
AMPL 60 DB
VCA -3 to -60 DB
GAIN CONTROL
DIST AMPL
HG X4
VCO OUT
FROM G.C. SWITCH
GAIN CONT AMPL
LOW PASS FILTER
EMITTER FOLLOWER
GAIN (SWITCHED WITH NOISE BW)
MANUAL GAIN
SLOPE & DELAY CONTROL
AMPL EMITTER FOLLOWER
GAIN
DELAY
SLOPE
TO MONOPULSE RECEIVER
PL 2 BL (CPS) 100, 300 1000, 3000
LC VCO 16 MC
INTEGRATOR
BW CONT
EXT VCO CONT
VCO FREQ INDICATOR
MANUAL TUNING
VCO FREQ OUT
AGC METER
GAIN ADJUST (FEEDBACK) 0 to 27 DB
AFC Bn (CPS) 100, 300, 1000, 3000
LC VCO 20 MC
SWEEP
MANUAL GAIN CONT
CRYSTAL VCO 20 MC
FROM PLL PHASE DET EF
FROM 2ND IF DISC
-90 PHASE SHIFTER LIMITER
QUAD PHASE DET
PL 2 BL (CPS) 1, 3, 10, 30, 100
MULTIPLIER X4
LPF
SCHMIDT TRIGGER
SWITCH HOLD
SWEEP OSC
2 BL (CPS) 3, 10, 30, 100 300, 1000
ENABLE
PERIOD
DEVIATION
1 MC
STALO
DISTR AMPL 5 MC
LIMITER
TO PLL PHASE
5 MC
STALO OUTPUT
5 MC TO MONOPULSE RECEIVER

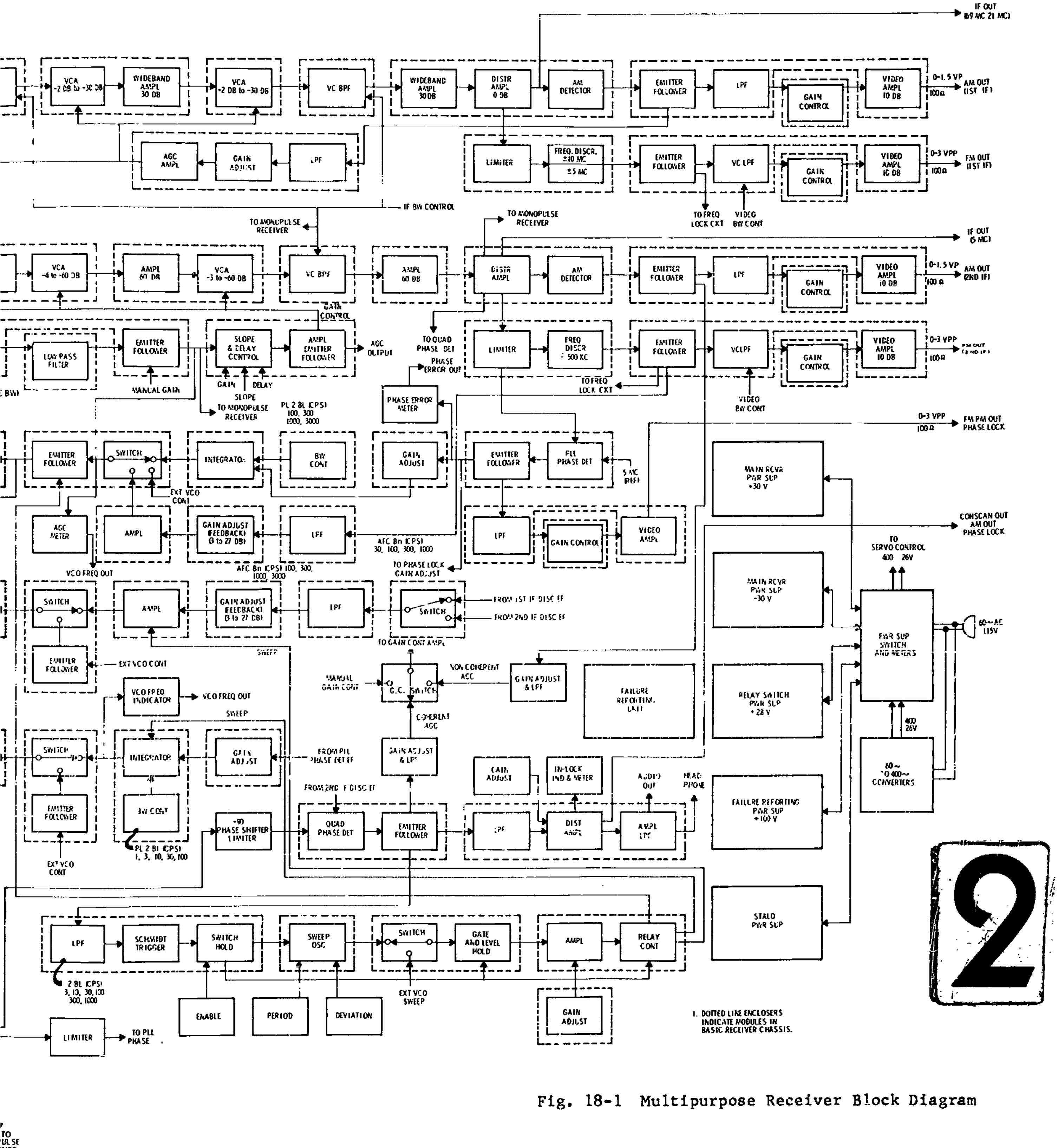


Fig. 18-1 Multipurpose Receiver Block Diagram

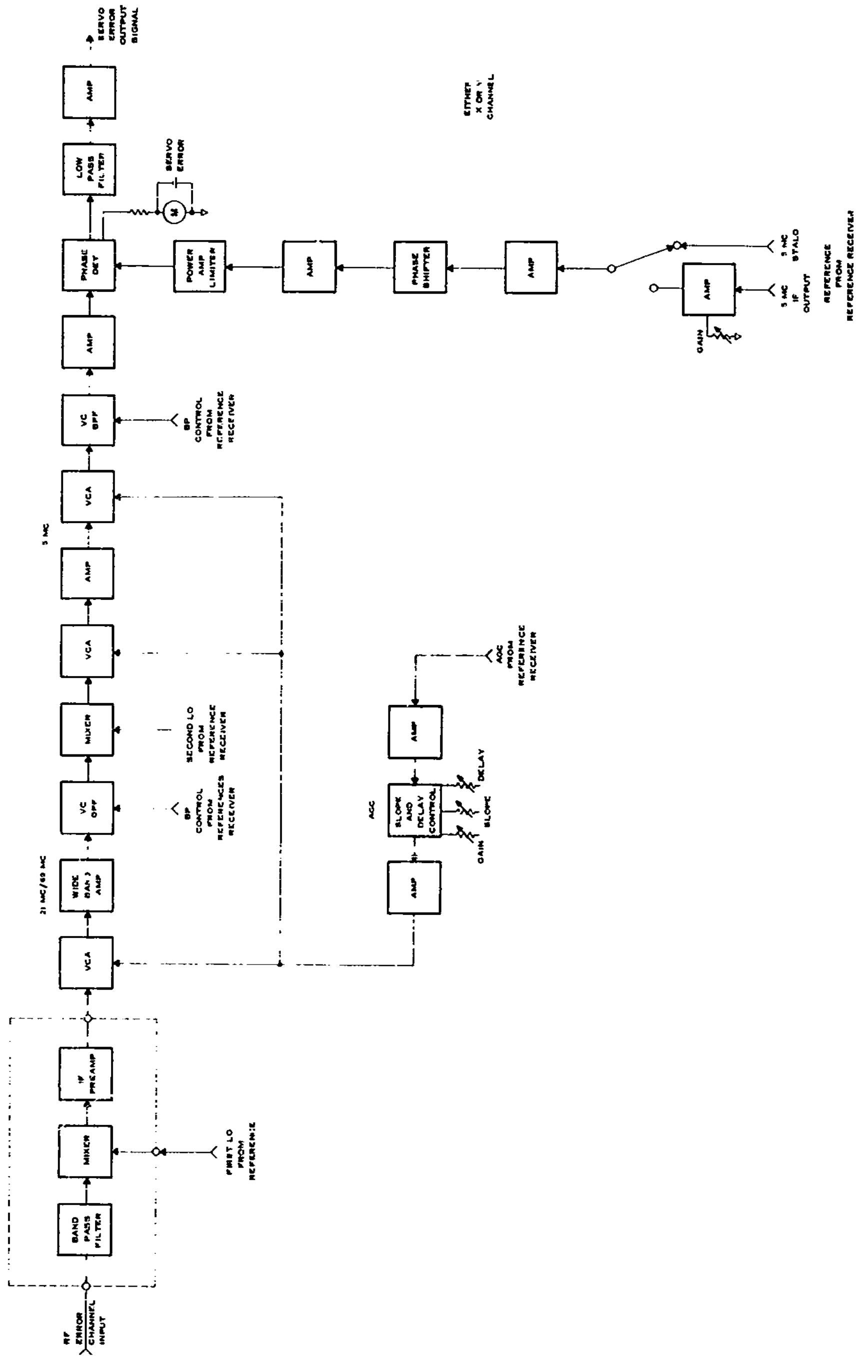


Fig. 18-2 Monopulse Part of Multipurpose Receiver

The AGC circuits include correlated (used with phase lock), uncorrelated, and manual modes of operation.

The acquisitions sweep circuits can be used with phase and frequency lock to assist in acquiring the input signal.

A summary of the alternate functions for the receiver operation is shown in Table 18-1.

TABLE 18-1

SUMMARY OF BASIC RECEIVER OPERATION

DETECTION	CONVERSION	R-F BANDWIDTH	MIXER FEEDBACK POINT
FM	1	20 mc	
	2	1 mc	
AM	1	20 mc	
	2	1 mc	
PHASE LOCK	2	100, 300, 1000, 3000 cps	2
	2	1,3,10,30, 100 cps	1
FMFB		7 mc	2
	1,2	30 mc*	1

* Can be obtained up to 100 mc at 3 Gc and higher with a change in R-F Head.

18.3 FREQUENCY SYNTHESIZER AND HARMONIC GENERATORS

The frequency synthesizer and the harmonic generators referenced to a STALO comprise the method for tuning the receiver. Each of these units are mounted in a single chassis drawer. The synthesizer tunes over an octave of frequency change with a resolution for discrete frequencies of 1×10^{-6} of the output frequency. The tuning of the receiver using the synthesizer is easily accomplished using dials on the front panel.

An array or matrix of harmonic generators is necessary for tuning the receiver from 100 mc to 10 Gc. The rows of the matrix represent frequency bands and the columns represent tuning within the frequency bands. The design allows for all or part of the array to be mounted in the single chassis drawer depending on the customers' desire. The switching of the harmonic generator array is performed automatically when tuning the frequency synthesizer.

18.4 FAILURE REPORTING AND ISOLATION SYSTEM (FRIS)

The failure reporting and isolation system is used to determine the location of a failure in order to restore operation in a minimum time period. Some of the receiver can be purchased equipment (STALO from Hewlett-Packard) and therefore may not be modularized. The units designed at Philco will be modularized and, by using the FRIS, faults can be located to the module.

18.5 REMOTE CONTROL

Remote control -- in as far as the specific receiver design is concerned -- is a capability. This means that controllers will be connected to all the "operator type" controls with their control leads wired to an output connector. The means for programming the remote control of the receiver is not (at least at this time) included in the receiver design.

It is therefore possible to operate the receiver completely from a remote position whether it be a distance of 10 feet or 3000 miles.

18.6 MONOPULSE RECEIVER AND R-F HEAD

The monopulse error channels are located in a single chassis drawer. They include the I-F amplifiers, AGC circuits and phase detectors. The units are capable of operating with phase lock or non phase lock (reference I-F output directly). Two additional r-f heads are needed with monopulse. These with the reference channel r-f head comprise a single chassis drawer.

18.7 OPERATING CONTROLS AND FRONT PANELS

Front panel drawings showing the controls for the receiver are shown in Figures 18-3 through 18-9. The details of the controls and their functions are described in charts at the end of the section. Figure 18-10 is a flow diagram for operator action. The flow diagram describes what the operator must do to control the receiver manually.

18.8 INPUTS AND OUTPUTS

The receiver is designed to be versatile with potential for growth. To accomplist this goal, there are certain features that should be included in the original receiver design.

In particular, all of the VCO's shall have external inputs to permit them to be controlled for frequency hopping systems and by a computer. For the case where external oscillators are preferred, all LO chains should accept external oscillator signal inputs.

The receiver must be used to its maximum capability to assist in external system operation and monitoring. Therefore all I-F amplifier signals (for predetection recording), AGC signals, phase error and in-lock signals should be available as receiver outputs.

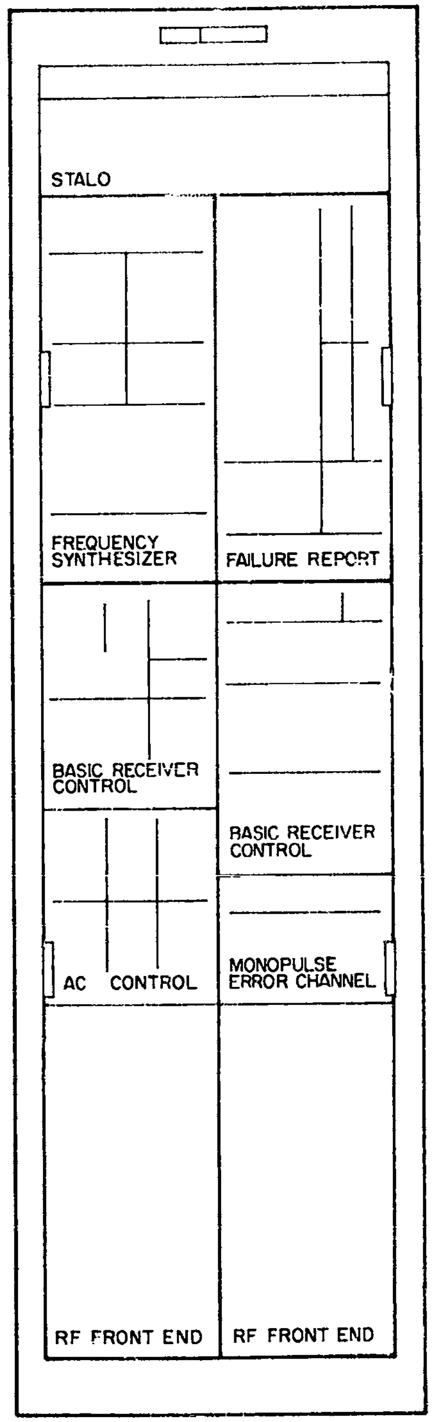


Fig. 18-3 Front Elevation

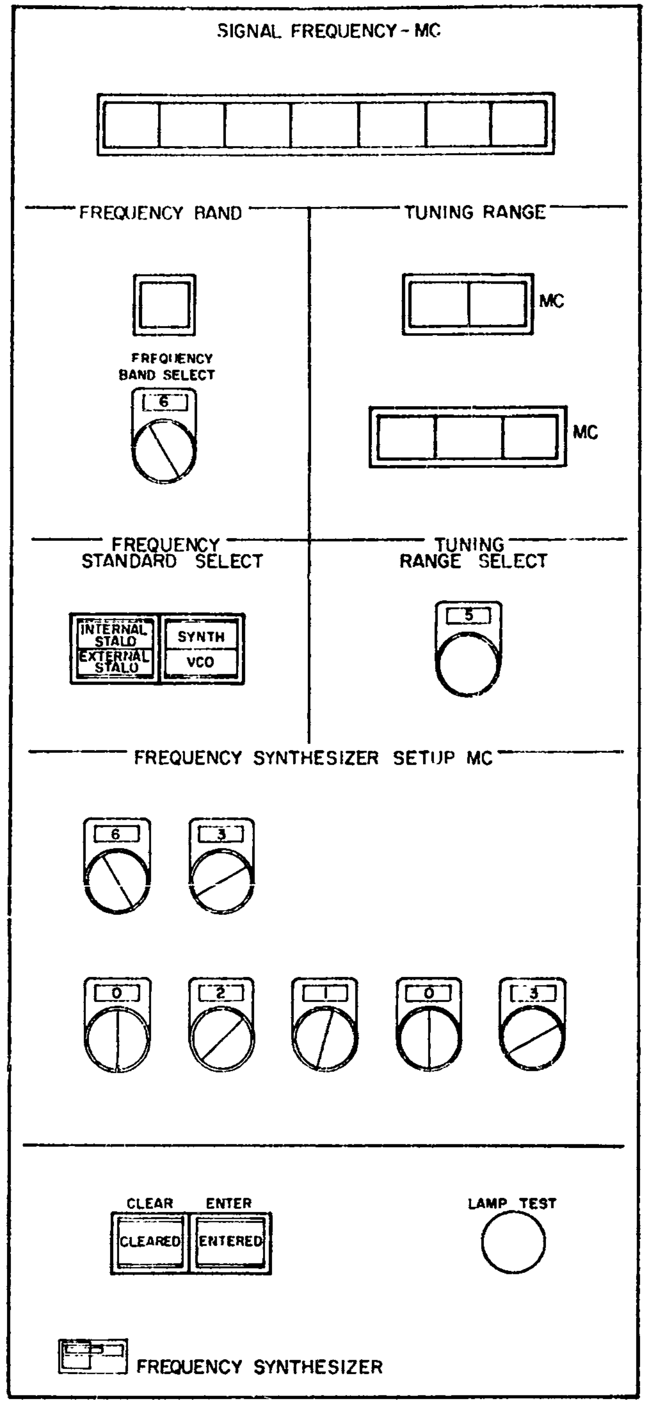


Fig. 18-4 Frequency Synthesizer Panel Layout

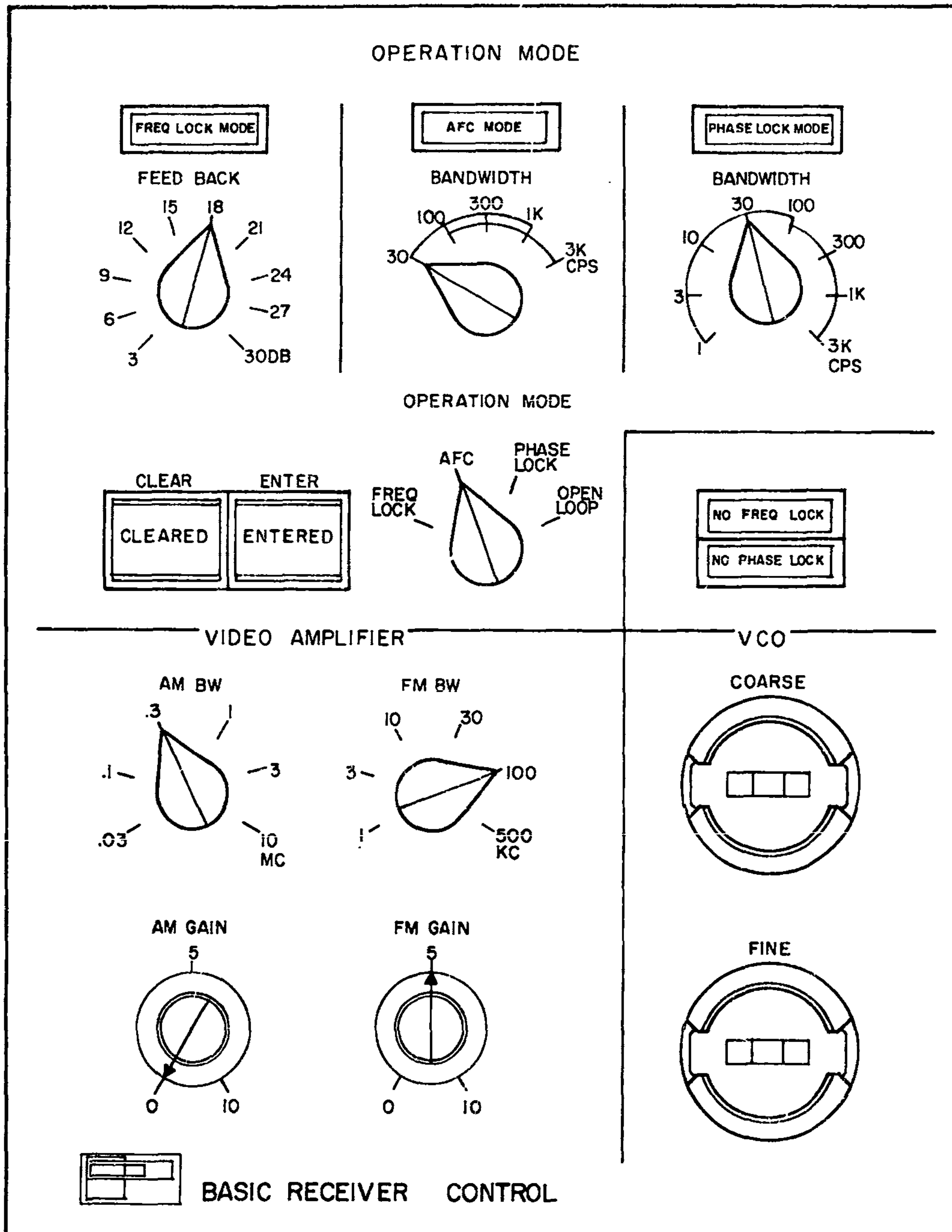


Fig. 18-5 Basic Receiver Control Panel Layout

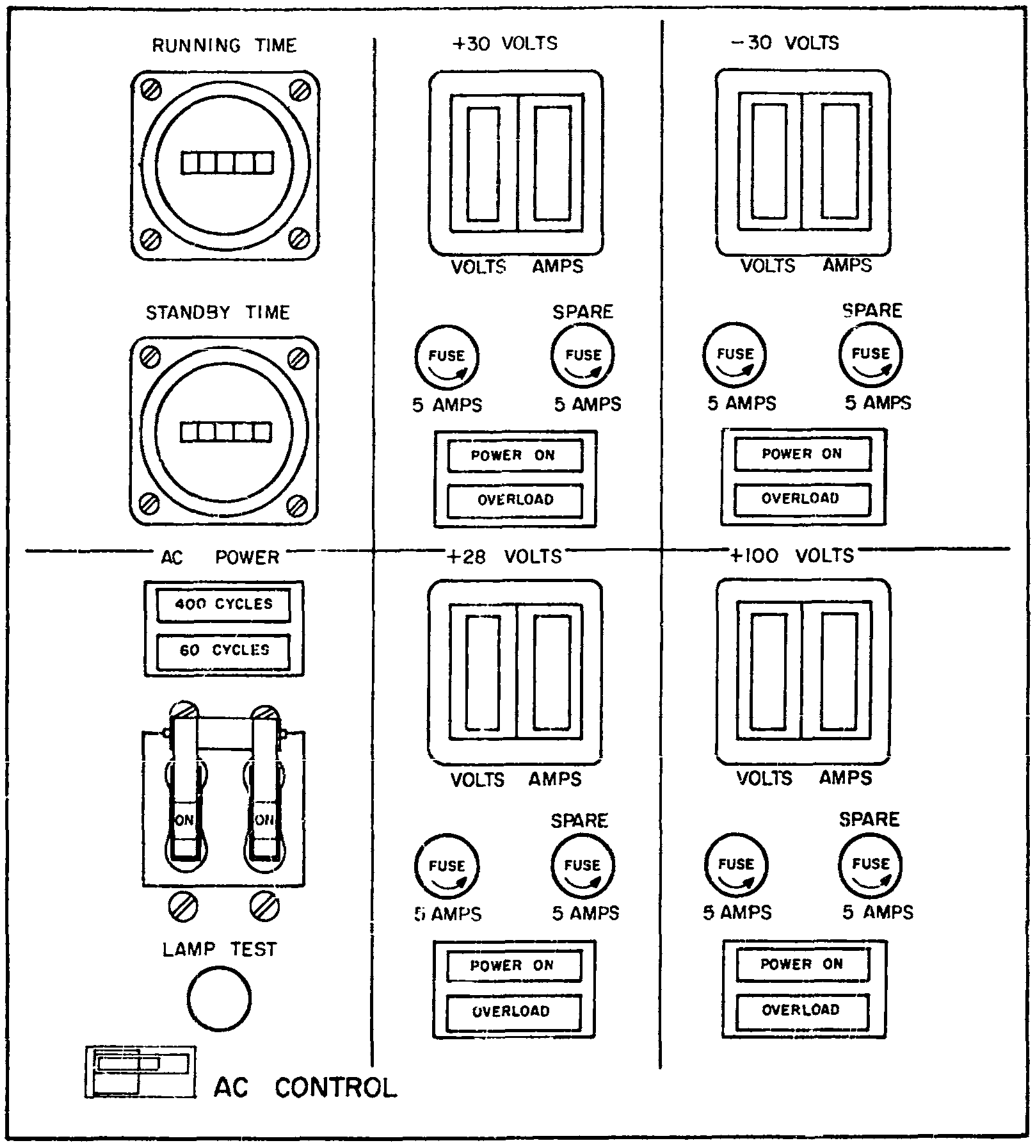


Fig 18-6 A-C Control Panel Layout

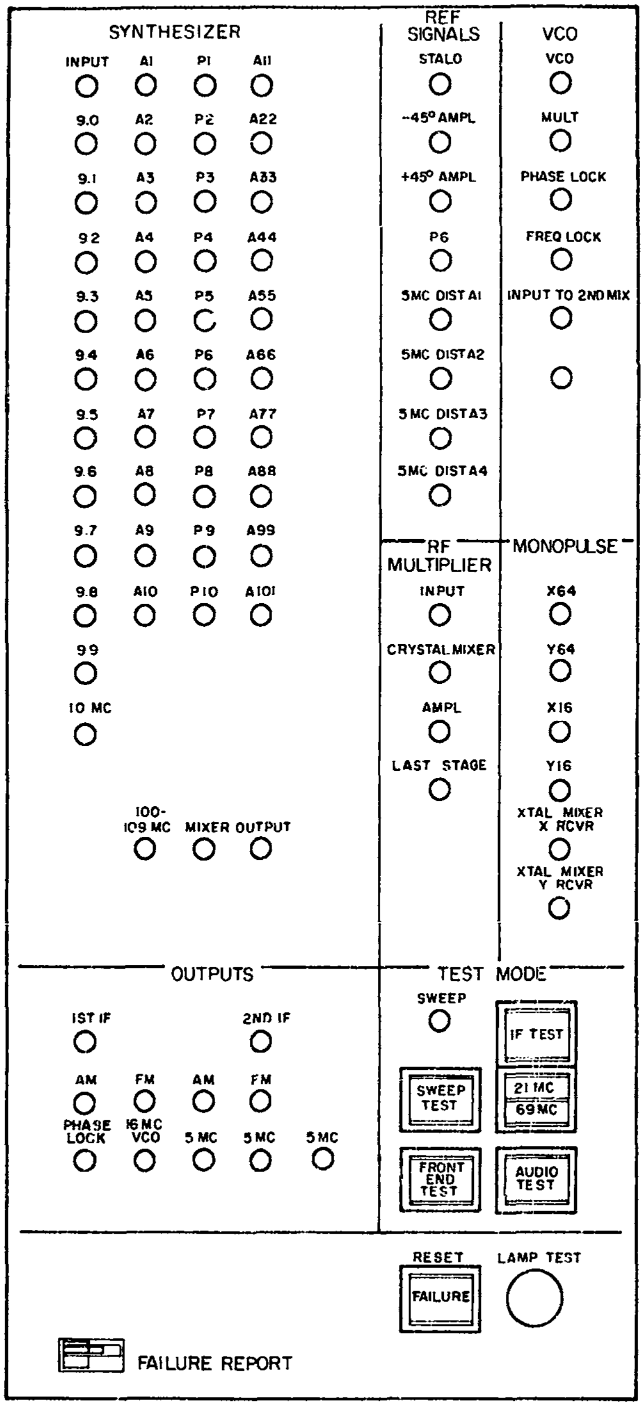


Fig. 18-7 Failure Reporting Panel Layout

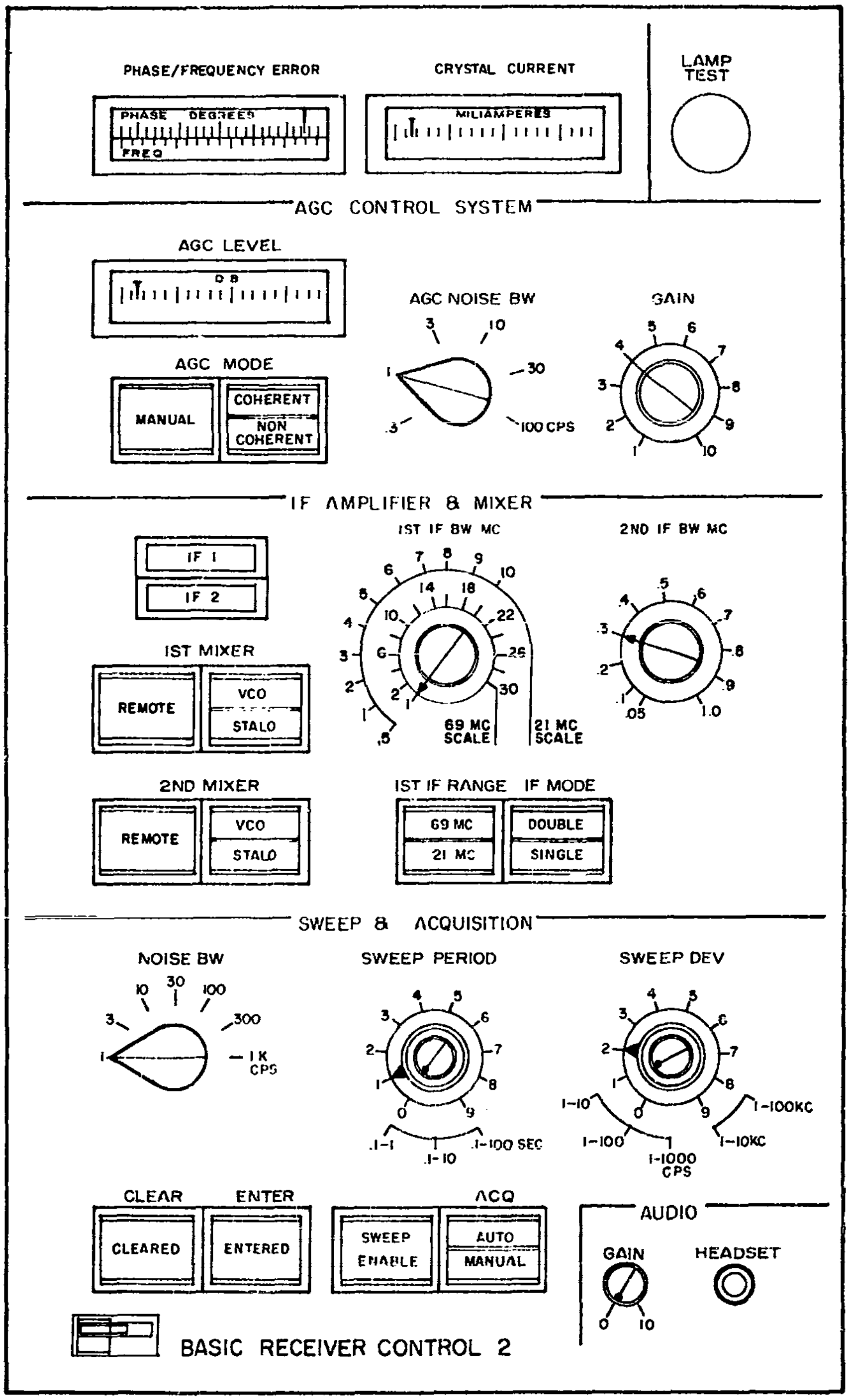


Fig. 18-8 Basic Receiver 2 Panel Layout

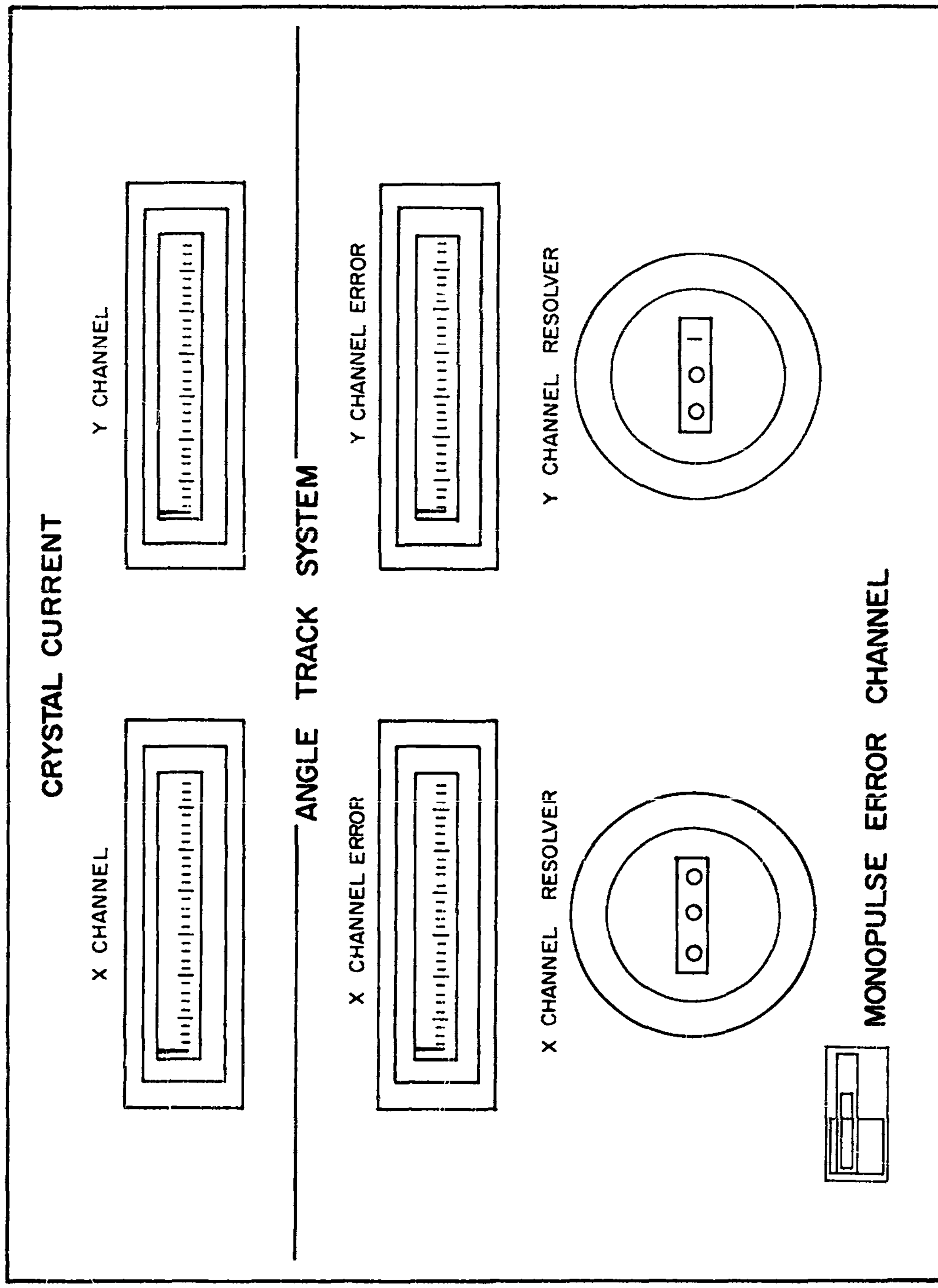


Fig. 18-9 Monopulse Error Channel Panel Layout

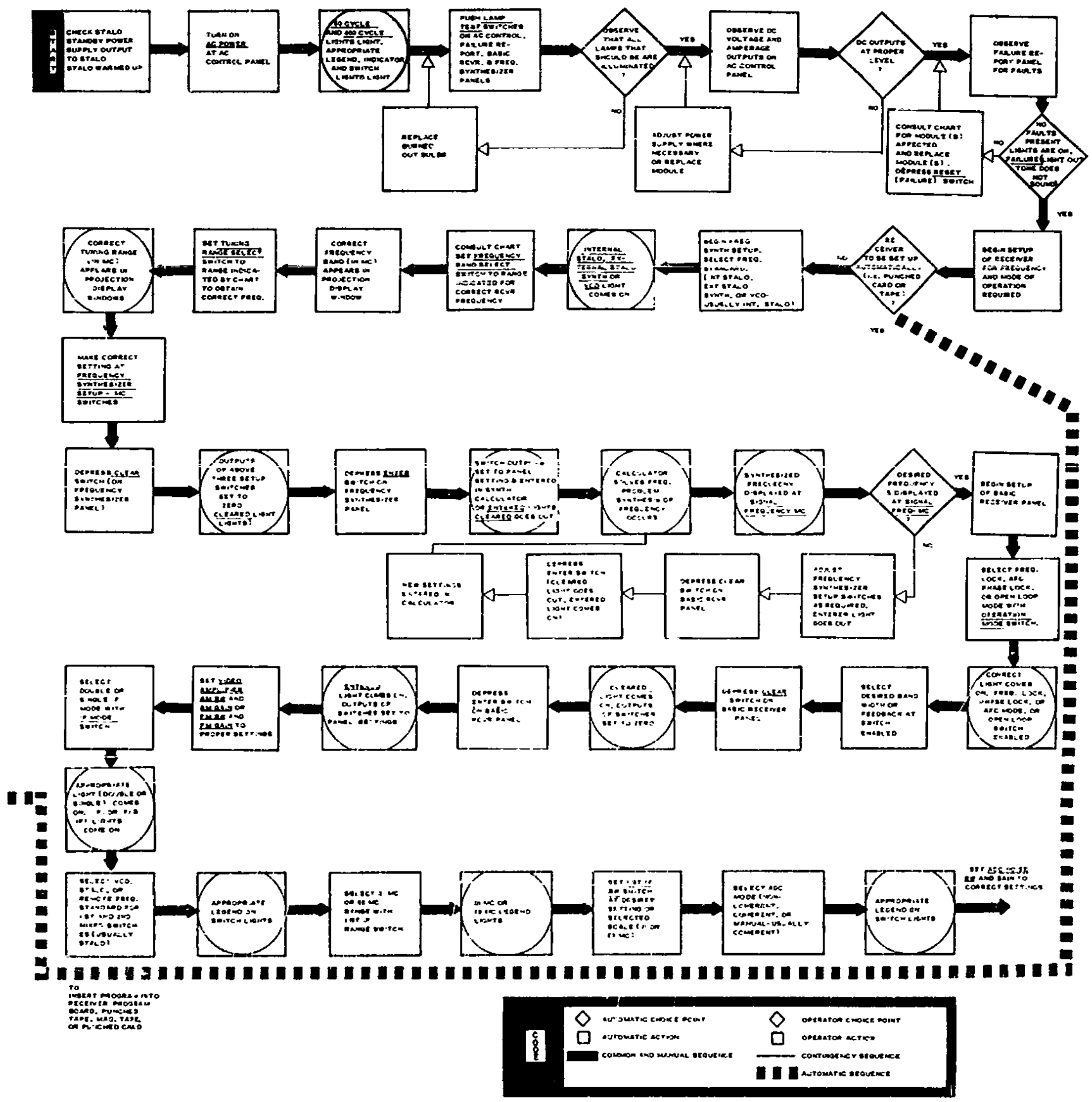


Fig 18-10 Operator Action Flow Chart

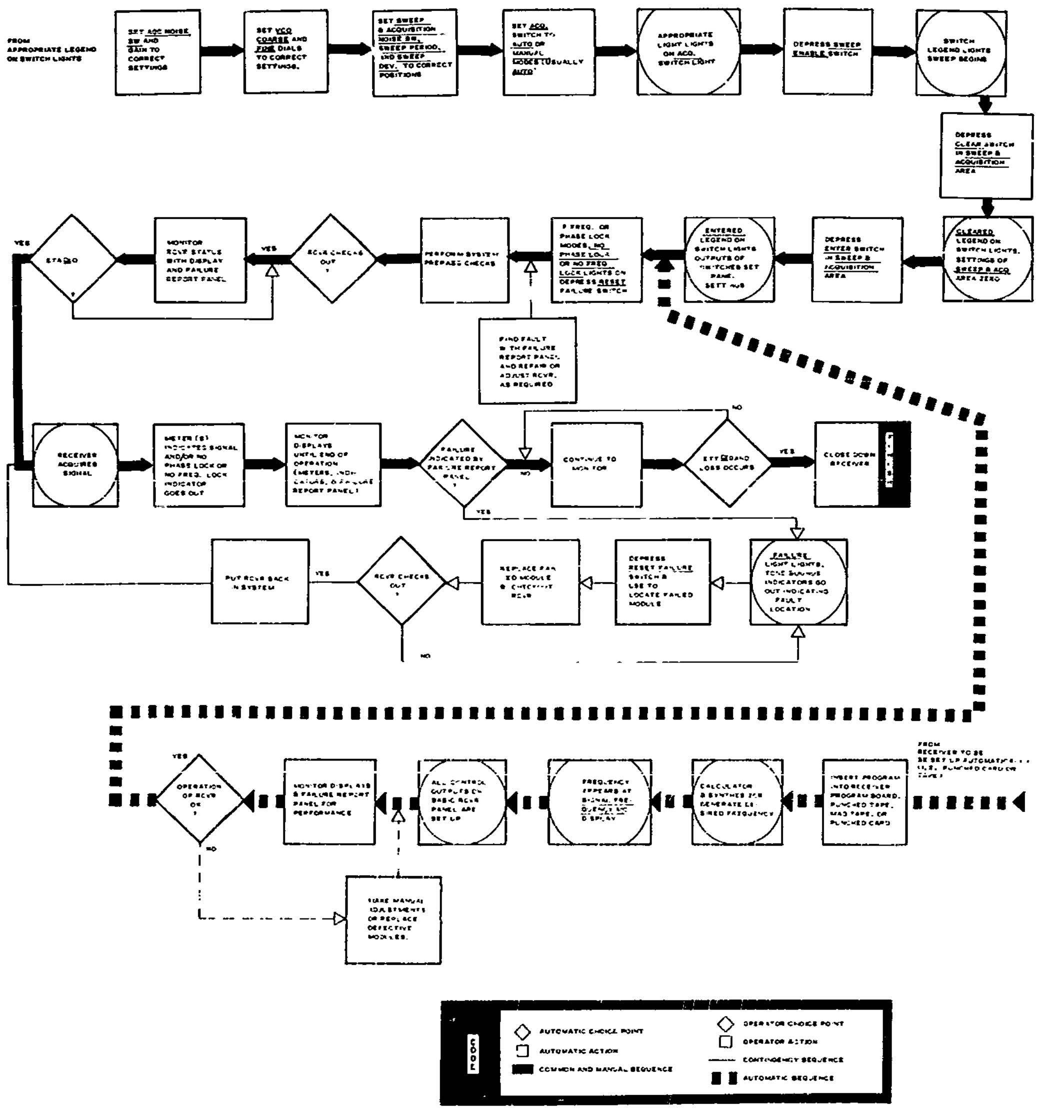


Fig. 18-10 Continued

TABLE 18-2

PANEL FUNCTION LIST
FAILURE REPORTER, MULTIPURPOSE RECEIVER

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
SYNTHESIZER GROUP	INPUT	Light, indicator, white lens (neon)	Indicates, when on, presence of proper STALO output.	STALO
	9.0 9.1 9.2 9.3 9.4 9.5 9.6 9.7 9.8 9.9 10 mc	Light, indicator white lens (neon)	Indicates, when on, the presence within the synthesizer of the signal indicated.	Synthesizer internal circuitry

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
SYNTHESIZER GROUP	A 1 A 2 A 3 A 4 A 5 A 6 A 7 A 8 A 9 A 10	Light, indicator, white lens (neon)	Indicates, when on, presence of correct output from amplifier designated.	Outputs of synthesizer internal amplifiers.
	P 1 P 2 P 3 P 4 P 5 P 6 P 7 P 8 P 9 P 10	Light, indicator, white lens (neon)	Indicates, when on, presence of correct output from phase designated.	Outputs of synthesizer internal phase detectors.

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
SYNTHESIZER GROUP	A 11 A 22 A 33 A 44 A 55 A 66 A 77 A 88 A 99 A 101	Light, indicator, white lens (neon)	Indicates, when on, the presence of the correct output from the amplifier designated.	Outputs of synthesizer internal amplifier.
	100-109 mc	Light, indicator, white lens (neon)	Indicates, when on, the presence of the correct output from this amplifier.	Output of internal amplifier of final stage of synthesizer.
	MIXER	Light, indicator, white lens (neon)	Indicates, when on, the presence of the correct output from mixer.	Output of internal mixer in the final stage of the synthesizer.
	OUTPUT	Light, indicator, white lens (neon)	Indicates, when on, the presence of the correct output from the synthesizer.	Output of synthesizer.

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
REFERENCE SIGNALS GROUP	STALO	Light, indicator, white lens (neon)	Indicates, when on, the presence of correct STALO output.	Output of STALO.
	-45^{o} AMPL	Light, indicator white lens (neon)	Indicates, when on, the presence of correct output of -45^{o} amplifier.	Output of -45^{o} amplifier.
	$+45^{o}$	Light, indicator, white lens, neon	Indicates, when on, the presence of correct output of $+45^{o}$ amplifier.	Output of $+45^{o}$ amplifier.
	P S	Light, indicator, white lens, neon	Indicates, when on, the presence of output from power supply or supplies.	Output of power supply or power supplies, anded if more than one.
	5 mc DIST A 1	Light, indicator, white lens, neon	Indicates, when on, the presence of output from 5 mc distributor A 1.	Output of 5 mc distributor A 1.
	5 mc DIST A 2	Light, indicator, white lens, neon	Indicates, when on, the presence of output from the 5 mc distributor A 2.	Output of 5 mc distributor A 2.

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
REFERENCE SIGNALS GROUP	5 MC DIST A 3	Light, indicator, white lens, neon	Indicates, when on, the presence of output from the 5 mc distributor A 3.	Output of 5 mc distributor A 3.
	5 MC DIST A 4	Light, indicator, white lens, neon	Indicates, when on, the presence of output from the 5 mc distributor A 4.	Output of 5 mc distributor A 4.
RF MULTIPLIER GROUP	INPUT	Light, indicator white lens, neon	Indicates, when on, presence of correct input to RF multiplier.	Output of amplifier which receives signal from synthesizer.
	CRYSTAL MIXER	Light, indicator, white lens, neon	Indicates, when on, presence of correct output from crystal mixer.	Output of RF multiplier crystal mixer.
	AMPL	Light, indicator, white lens, neon	Indicates, when on, presence of correct output from RF multiplier amplifier.	Output of RF multiplier amplifier.
	LAST STAGE	Light, indicator, white lens, neon	Indicates, when on presence of correct output from last stage.	Output of RF multiplier last stage.

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
VCO GROUP	VCO	Light, indicator, white lens, neon	Indicates, when on, presence of correct VCO signal.	Last stage of VCO amplifier.
	MULT	Light, indicator, white lens, neon.	Indicates, when on, presence of correct output from VCO multiplier strip.	VCO multiplier strip
	PHASE LOCK	Light, indicator, white lens, neon	Indicates, when on, correct operation of phase lock circuit within perscribed limits.	Impedance of phase lock circuit.
	FREQ LOCK	Light, indicator, white lens, neon.	Indicates, when on, correct operations of frequency lock circuit within perscribed limits.	Impedance of frequency
	INPUT TO 2ND MIXER	Light, indicator, white lens, neon.	Indicates, when on, presence of correct VCO multiplier output signal.	Output of VCO multiplier
MONOPULSE GROUP	X 64	Light, indicator, white lens, neon.	Indicates, when on, times 64 X channel is functioning.	VCO
	Y 64	Light, indicator, white lens, neon.	Indicates, when on, times 64 Y channel is functioning.	VCO

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
MONOPULSE GROUP	X 16	Light, indicator, white lens, neon.	Indicates, when on, that times 16 X Channel is functioning.	VCO
	Y 16	Light, indicator, white lens, neon.	Indicates, when on, that times 16 Y Channel is functioning.	VCO
	X TAL MIX X RCVR	Light, indicator, white lens, neon	Indicates, when on, that RF crystal current to X receiver is functioning	RF multiplier
	X TAL MIX Y RCVR	Light, indicator, white lens, neon.	Indicates, when on, that RF crystal current input to Y receiver is functioning.	RF multiplier
OUTPUTS GROUP	1ST IF	Light, indicator, white lens, neon.	Indicates, when on, output of 21 or 69 mc is present.	1st IF
	2ND IF	Light, indicator, white lens, neon.	Indicates, when on, that an output of 5 mc is present.	2nd IF
	AM	Light, indicator, white lens, neon.	Indicates, when on, output of demodulated AM is present from 1st IF.	IF Preamplifier

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
OUTPUTS GROUP (Continued)	FM	Light, indicator, white lens, neon.	Indicates, when on, output of demodulated FM is present from 1st IF.	IF Preamplifier
	AM	Light, indicator, white lens, neon.	Indicates, when on, output of demodulated AM is present from 2nd IF.	2nd mixer
	FM	Light, indicator, white lens, neon.	Indicates, when on, output of demodulated FM is present from 2nd IF.	2nd mixer
	PHASE LOCK	Light, indicator, white lens, neon.	Indicates, when on, that phase lock has occurred.	Acquisition circuits.
	VCO	Light, indicator, white lens, neon.	Indicates, when on, presence of VCO output.	VCO
	5 mc	Light, indicator, white lens, neon.	Indicates, when on, presence of 5 mc outputs for monopulse system.	5 mc distribution amplifier.
	5 mc	Light, indicator, white lens, neon.	Indicates, when on, presence of 5 mc output.	5 mc distribution amplifier

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
TEST MODE GROUP	FRONT END TEST	Switch, pushbutton, momentary illuminated legend, yellow when lighted.	Activates receiver front end test.	N/A
	AUDIO TEST	Switch, pushbutton, alternate action, illuminated legend, yellow when lighted.	Activates receiver audio test.	N/A
	SWEEP TEST	Switch, pushbutton momentary, illuminated legend, yellow when lighted.	Activates receiver sweep test	N/A
	SWEEP TEST	Light, indicator, white lens, neon.	Indicates, when on, that results of sweep test are positive.	Sweep circuitry
	IF TEST	Switch, pushbutton, momentary, illuminated legend, yellow when lighted.	Activates receiver IF test on basis of 21 mc or 69 mc selected by switch below.	N/A
	21 mc	Switch, pushbutton, momentary split, dual illuminated legend, white when lighted.	Selects either 21 mc or 69 mc for the IF test. Either 21 mc or 69 mc is always illuminated.	N/A

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TABLE 18-2 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
TEST MODE GROUP (Continued)	FAILURE RESET	Switch, pushbutton, momentary, illuminated legend, blinks red when lighted, also horn or tone.	Calls attention to a failure indication on panel by blinking red light and horn or tone. Red light and tone stopped by depressing switch.	Sensing of a failure reported by indicator or indicators going out on panel.
	LAMP TEST	Switch, pushbutton, momentary.	Tests bulbs in indicators and legends for burn out.	N/A

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TABLE 18-3

PANEL FUNCTION LIST
FREQUENCY SYNTHESIZER, MULTIPURPOSE RECEIVER

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
SIGNAL FREQUENCY-mc	SIGNAL FREQUENCY-mc) through 9 and decimal point.	Decimal readout indicator, lighted, projection, eleven positions. 7 each.	Displays receiver frequency set up as a result of synthesis process based on panel control settings or computer inputs.	Synthesizer logic.
	CLEAR	Switch, pushbutton, momentary, illuminated legend, yellow when lighted.	Zero sets panel setup switches which are controlled at this panel Enables setup at panel.	N/A
	CLEARED	Legend light on above switch.	Indicates, when on, that above switches are zero set.	Sensed at switch zero or null positions
	ENTER	Switch, pushbutton, momentary, illuminated legend, white when lighted.	Enter outputs of panel setup switches as shown at panel	N/A
	ENTERED	Legend light on above switch.	Indicates that setup switch outputs are as indicated at panel.	Sensed at switches when panel settings agree with switch outputs.
FREQUENCY STANDARD SELECT group	INTERNAL STALO EXTERNAL STALO	Switch, pushbutton, solenoid held, illuminated split, dual legend, white when lighted.	Selects internal STALO, external STALO, synthesizer or VCO as the frequency standard to be used.	N/A
FREQUENCY STANDARD SELECT group (Continued)	SYNTH VCO	Switch, pushbutton, solenoid held, illuminated split dual legend, white when lighted.		N/A

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TABLE 18-3 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
FREQUENCY BAND group	FREQUENCY BAND-MC	Indicator, decimal readout, lighted, projection, eight (8) groups of frequency ranges.	Displays one of eight broad frequency ranges selected by the FREQUENCY BAND SELECT switch.	Output of FREQUENCY BAND SELECT switch.
	FREQUENCY BAND SELECT 1, 2, 3, 4, 5, 6, 7, 8.	Switch, rotary, eight (8) position.	Selects one of eight broad frequency ranges for synthesis process, ranges are displayed at above unit. Numbers 1 thru 8 are for quick correlation with chart.	N/A
TUNING RANGE group	TUNING RANGE-MC	Indicator, decimal readout, lighted projection, five (5) each.	Displays one of 59 narrow frequency ranges.	Combined outputs of FREQUENCY BAND SELECT and TUNING RANGE SELECT switches.
	TUNING RANGE SELECT	Switch, rotary eight(8) position.	Selects, depending upon the position of the FREQUENCY BAND SELECT switch, one of 59 narrow frequency ranges for synthesis process.	N/A
			Ranges are displayed on above units. Numbers 1 thru 8 enable quick correlation with chart.	

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TABLE 18-3 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
FREQUENCY SYNTHESIZER SETUP-MC	FREQUENCY SYNTHE-SIZER SETUP-MC 0 thru 9	Switch, rotary ten (10) position, 7 each	Provides fine tuning to the frequency to be received.	N/A
	LAMP TEST	Switch, pushbutton, momentary	Tests bulbs in legend lights for burn out.	N/A

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TABLE 18-4

PANEL FUNCTION LIST
MONOPULSE ERROR CHANNEL, MULTIPURPOSE RECEIVER

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
ANGLE TRACK SYSTEM	X CHANNEL ERROR	Meter	Indicates X channel error in degrees	X Channel Phase detector
	X CHANNEL RESOLVER	Resolver, 360° with ten (10) to one (1) control knob.	Adjusts X channel phase shift.	N/A
	Y CHANNEL RESOLVER	Resolver, 360° with ten (10) to one (1) control knob.	Adjusts Y channel error in degrees.	Y Channel Phase detector
	Y CHANNEL ERROR	Meter	Indicates Y channel error in degrees.	Y Channel Phase detector
CRYSTAL CURRENT	X CHANNEL	Meter	Indicates crystal current from 1st mixer in X channel.	1st mixer in X channel
	Y CHANNEL	Meter	Indicates crystal current from 1st mixer in Y channel.	1st mixer in Y channel

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TABLE 18-5

PANEL FUNCTION LIST
BASIC RECEIVER, MULTIPURPOSE RECEIVER

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
OPERATION MODE area	OPERATION MODE FREQ. LOCK	Switch, rotary, four (4) position	Selects on of four modes of receiver operation	N/A
	AFC PHASE LOCK OPEN LOOP			
	FREQ LOCK MODE	Light, legend, white when lighted.	Indicates frequency lock mode of receiver operation is selected.	OPERATION MODE switch in FREQ LOCK position or FREQ LOCK mode selected by computer.
	(FREQ LOCK) FEEDBACK 3,6,9,12,15, 18,21,24,27, and 30 DB	Switch, rotary ten (10) position.	Selects frequency lock mode feedback bandwidth.	N/A
	AFC MODE	Light, legend, white when lighted.	Indicates AFC mode of receiver operation is selected.	OPERATION MODE switch in AFC position or AFC mode selected by computer.
	(AFC) BANDWIDTH 30, 100, 300 1K and 3K CPS	Switch, rotary, five (5) position.	Selects tracking bandwidth for AFC mode.	N/A
	PHASE LOCK MODE	Light, legend, white lens.	Indicates mode of receiver operation selected	OPERATION MODE Switch in PHASE LOCK position or PHASE LOCK mode selected by computer.

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TABLE 18-5 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
OPERATION MODE area	PHASE/FREQUENCY ERROR	Meter, dual scale	Indicates magnitude of phase or frequency error depending on which mode is selected.	Phase detector or frequency detector
	NO PHASE LOCK	Light, legend, red when lighted.	Indicates, when receiver in in phase lock mode, that no phase lock exists	Acquisition circuits.
	NO FREQ LOCK	Light, legend, red when lighted.	Indicates, when receiver in in frequency lock mode that no frequency lock exists.	Acquisition circuits.
AUDIO group	GAIN 1 thru 10	Potentiometer,	Controls gain of audio signal.	N/A
	HEADSET	Jack, coaxial, for headset.	Enables plug in of head-set to allow operator to audibly sense quality of signal.	Audio amplifier
VIDEO AMPLIFIER group	AM BW .03,.1,.3,1,3, 10 MC	Switch, rotary, six (6) position	Selects AM base band bandwidth.	N/A
	AM GAIN 1 thru 10	Potentiometer, 300° throw.	Controls gain of AM video amplifier	N/A
	FM BW 1,3,10,30,100 500 KC	Switch, rotary, six (6) position.	Selects FM base band bandwidth.	N/A

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TABLE 18-3 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
OPERATION MODE area (continued)	(PHASE LOCK) BANDWIDTH 1,3,10,30,100,300, 1K, and 3K CPS	Switch, rotary, eight (8) position.	Selects phase lock bandwidth for PHASE LOCK mode.	N/A
	CLEAR	Switch, pushbutton, momentary, illuminated, legend, yellow when lighted.	Zero sets functions controlled by OPERATION MODE FREQ LOCK, FEEDBACK, AFC BANDWIDTH, and PHASE LOCK BANDWIDTH switches. Enables set-up at panel.	N/A
	CLEARED	Legend light on above switch.	Indicates functions above have been zero set. Goes out when ENTER switch is depressed.	Sensed at switch outputs when at zero set.
	ENTER	Switch, pushbutton, momentary, illuminated legend, white when lighted.	Enters settings of above four mode switches as shown at panel. Enabled by CLEAR switch.	N/A
	ENTERED	Legend light on above switch.	Indicates that above four mode switches are at settings shown by panel knobs.	Fact that knob settings agree with switch positions.
	CRYSTAL CURRENT	Meter	Indicates crystal current in milli-amperes.	Diode in first mixer.

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TABLE 18-5 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
VIDEO AMPLIFIER group (continued)	FM GAIN 1 thru 10	Potentiometer, 300° throw.	Controls gain of FM video amplifier	N/A
IF AMPLIFIER AND MIXER group	1st I-F RANGE 21 mc 69 mc	Switch, pushbutton, momentary, illuminated, split double legend, white when lighted. Momentary switch activates series of relays.	Selects 21 MC or 69 MC scale output at 1st IF BW-MC switch.	N/A
	I-F MODE DOUBLE SINGLE	Switch, pushbutton, momentary, illuminated, split double legend, white when lighted. Momentary switch activates series of relays.	Selects either single or double frequency conversion.	N/A
	1st MIXER VCO STALO REMOTE	Switch, pushbutton, momentary, illuminated, split triple legend, white when lighted. Momentary switch activates series of relays.	Selects VCO, STALO or some other remote oscillator to drive first mixer.	N/A
	2nd MIXER VCO STALO REMOTE	Switch, pushbutton, momentary, illuminated, split triple legend, white when lighted. Momentary switch activates series of relays.	Selects VCO, STALO, or some other remote oscillator to drive second mixer.	N/A

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TABLE 18-5 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
IF AMPLIFIER & MIXER group (continued)	1ST IF BW-MC .5MC thru 10MC and 1MC thru 30MC	Switch, rotary, 11 position and 16 position.	Selects IF pass band for 1st IF Amplifier. Either 21 MC or 69 MC scale selected by 1st IF Range switch.	N/A
	2ND IF BW-MC .05 MC to 1 MC	Switch, rotary, 11 position	Selects IF pass band for 2nd IF Amplifier	N/A
AGC CONTROL SYSTEM	AGC MODE NON COHER COHERENT MANUAL	Switch, pushbutton, momentary, illuminated split triple legend, Momentary switch activates a series of relays	Selects non-coherent, coherent, or manual AGC modes.	N/A
	AGC NOISE BW .3,1,3,10,30, 100 CPS	Switch, rotary, six (6) position.	Sets noise band width of AGC Amplifier.	N/A
	GAIN 1 thru 10	Potentiometer, 300° throw.	Sets noise band width of AGC Amplifier.	N/A
	AGC LEVEL	Meter	Indicates AGC level in DB.	AGC circuitry
	IF 1	Light, legend, white lens.	When on, indicates that Amplifier 1 has AGC applied.	IF MODE switch in single or double position.
	IF 2	Light, legend, white lens.	When on, indicates that amplifier 2 has AGC applied.	IF MODE switch in double position only.

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TABLE 18-5 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
AGC CONTROL SYSTEM (continued)	LAMP TEST	Switch, pushbutton momentary.	Tests bulbs in lighted indicators and legends for burn out.	N/A
VCO group	COARSE	Potentiometer, ten (10) turn.	Provides coarse frequency adjustment of the VCO	N/A
	FINE	Potentiometer, ten (10) turn	Provides fine frequency adjustment of the VCO	N/A
SWEEP AND ACQUISITION group	SWEEP ENABLE	Switch, pushbutton, momentary, illuminated legend, white when lighted.	Starts frequency search when search starts, legend illuminates.	N/A
	ACQ AUTO MANUAL	Switch, pushbutton, momentary, illuminated split double legend, white when lighted. Momentary switch activates series of relays.	Selects automatic or manual acquisition mode.	N/A
	NOISE BW 1,3,10,30,100, 300, 1K CPS	Switch, rotary, seven (7) position.	Selects noise bandwidth.	N/A
	SWEEP PERIOD .1-1, .1-10, .1-100, CPS and 0 thru 9	Switch, rotary, dual, coaxial. Three (3) position and ten (10) positon.	Coarse and fine controls set rated sweep period.	N/A

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TABLE 18-5 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
SWEEP AND ACQUISITION group	SWEEP DEV. 1-10, 1-100 1-10000 CPS 1-10KC 1.100 KC and 0 thru 9	Switch, rotary, dual, coaxial. Five (5) position and ten (10) position.	Coarse and fine controls set in frequency deviation of VCO.	N/A
	CLEAR	Switch, pushbutton, momentary, illuminated legend, yellow when lighted.	Zero sets functions of all switches in SWEEP AND ACQUISITION group. Enables setup at panel.	N/A
	CLEARED	Legend light on switch above.	Indicates functions of switches above have been zero set.	Sensed at switch outputs when at zero set.
	ENTER	Switch, pushbutton, momentary, illuminated legend, white when lighted.	Enters settings of switches above as shown at panel. Enabled by CLEAR switch.	N/A
	ENTERED	Legend light on switch above.	Indicates that switch outputs areas indicated at panel.	Panel settings agree with outputs of switches.

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TABLE 18-6

PANEL FUNCTION LIST
STALO STANDBY POWER SUPPLY, MULTIPURPOSE RECEIVER

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
	BATTERY VOLTAGE	Meter, DC volts	Indicates voltage output from power supply battery	Battery
	BATTERY CURRENT	Meter DC amperes	Indicates ampere output from power supply battery	Battery
OPERATING POWER	AC LINE	Light, indicator, white lens.	Indicates that STALO power is coming from AC line.	Sensed from position of relay controlling selection of power source.
	BATTERY	Light, indicator, white lens.	Indicates that STALO power is coming from battery in standby power supply.	
FUSE FAILURE	AC LINE	Light, indicator, red lens, two (2) each.	Indicates when on, that the respective fuse has blown.	Sensed from AC input when fuse blows.
	AC LINE 1.5 AMPS 1.6 AMPS	Fuse, 1.6 amp and socket. Two (2) each.	Protects AC circuits in power supply.	N/A
	SPARE	Fuse, 1.6 amp and holder, two (2) each.	Insures having spare fuse available.	N/A

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TABLE 18-7

PANEL FUNCTION LIST
AC CONTROL MULTIPURPOSE ANTENNA

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
	RUNNING TIME (HOURS)	Indicator, elapsed time.	Indicates total time AC power is applied to Receiver.	AC POWER on switch
	STANDBY TIME (HOURS)	Indicator, elapsed time.	Indicates total time power is applied to STALO, whether AC or DC	STALO
+ 30 VOLTS DC	VOLTS	Meter	Indicates voltage output of +30 volt power supply.	+30 volt power supply output.
	AMPS	Meter	Indicates amperage output of +30 volt power supply.	+30 volt power supply output.
	.5 AMPS	Fuse, .5 amps and socket.	Protects power supply circuitry from AC overload.	N/A
	SPARE .5 AMPS	Fuse, .5 amps and holder.	Insures having space available.	N/A
+30 VOLTS DC	POWER	Light, legend white when lighted.	Indicates, when on, presence of input to +30 VOLT DC power supply between fuse and rest of power supply.	Front end of +30 Volt DC power supply.
	OVERLOAD	Light, legend, yellow when lighted.	Indicates, when on, that an overload (marginal) condition exists.	Current limiting characteristic of power supply.

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TABLE 18-7 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
-30 VOLTS DC	VOLTS	Meter	Indicates voltage output of -30 volt power supply.	-30 volt power supply output.
	AMPS	Meter	Indicates amperage output of -30 volt power supply.	-30 volt power supply output.
	.5 AMPS	Fuse, .5 amps and socket.	Protects power supply circuiting from AC overload.	N/A
	SPARE .5 AMPS	Fuse, .5 amps and holder.	Insures having spare fuse available.	N/A
	POWER ON	Light, legend, white when lighted.	Indicates, when on, presence of input to -30 VDC power supply between fuse and rest of power supply.	Front end of -30 VDC power supply.
	OVERLOAD	Light, legend, yellow when lighted.	Indicates, when on, that an overload (marginal condition exists.	Current limiting characteristic of power supply.
+28 VOLTS DC	VOLTS	Meter	Indicates voltage output of +28 VOLT DC power supply.	+28 VOLT DC power supply output.
	AMPS	Meter	Indicates amperage output of +23 VOLT DC power supply.	+28 VOLT DC power supply output.

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TABLE 18-7 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
+28 VDC (continued)	5 AMPS	Fuse, 5 amperes, and socket.	Protects power supply circuitry from AC overload.	N/A
	SPARE 5 AMPS	Fuse, 5 amperes and holder.	Insures having spare fuse available.	N/A
	POWER ON	Light, legend, white when lighted.	Indicates, when on, presence of input to +28 VDC power supply between fuse and rest of power supply.	
	OVERLOAD	Light, legend, yellow when lighted.	Indicates, when on, that an overload (marginal) conditions exists.	Current limiting circuit of power supply.
+100 VOLTS DC	VOLTS	Meter	Indicates voltage output of +100 VOLT DC power supply.	+100 VOLT DC power supply output.
	AMPS	Meter	Indicates amperage output of +100 VOLT DC power supply.	+100 VOLT DC power supply output.
	.5 AMPS	Fuse, .5 amperes, and socket.	Protects power supply.	N/AA
	SPARE .5 AMPS	Fuse, .5 amperes, and holder.	Insures having spare fuse available.	N/A
	POWER ON	Light, legend, white when lighted.	Indicates, when on, presence of input to +100	Front end of +100 VDC power supply.

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TABLE 18-7 (Continued)

LOCATION	NOMENCLATURE	HARDWARE	FUNCTION	SIGNAL SOURCE
			VDC power supply between fuse and power supply.	
+100 VOLTS DC (continued)	OVERLOAD	Light, legend, yellow when lighted.	Indicates, when on, that an overload (marginal) condition exists.	Current limiting circuits of power supply.
AC POWER	400 CYCLES	Light, legend, white when lighted.	Indicates that the 400 cycle power required for servo system is on.	400 cycle power source
	60 CYCLES	Light, legend, white when lighted.	Indicates that 60 cycle power is being fed to DC power supplies.	Presence of 60 cycle AC power.
	AC POWER ON/OFF	Switch-CIRCUIT	Applies 60 cycle (or 400 cycle) power to DC power supplies.	N/A
	LAMP TEST	Switch, pushbutton, momentary.	Tests for burned out bulbs in legend lights.	N/A

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